This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

(

MAY 22 1908
★ Dr. JOHN S. BILLINGS.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

407526

# CONTRIBUTIONS
FROM THE
SANITARY RESEARCH LABORATORY
AND
SEWAGE EXPERIMENT STATION

VOLUME IV

REPRINTED PAPERS

BOSTON, MASSACHUSETTS
1908

VDI

For Dr. John S. Billings.

With the Compliments of the

Sanitary Research Laboratory and

Sewage Experiment Station

of the

Massachusetts Institute of Technology.

SEWAGE EXPERIMENT STATION

NEW YORK
PUBLIC
LIBRARY

VOLUME IV

REPRINTED PAPERS

BOSTON, MASSACHUSETTS
1908

107526

TABLE OF CONTENTS

Introduction: The Present Status of the Sewage-Disposal Problem. Acknowledgments. William T. Sedgwick, Director.

1. Disposal of Sewage. C.-E. A. Winslow. [Paper read at the Ninth Annual School for Instruction of Health Officers, Burlington, Vt., June 19, 1907. Bulletin, Vermont State Board of Health, Volume VIII, pages 3–12. September, 1907.]

2. Investigations on the Purification of Boston Sewage in Septic Tanks and Trickling Filters. 1905–07. C.-E. A. Winslow and Earle B. Phelps. [*Technology Quarterly*, Volume XX (1907), pages 387–452.]

3. A Method for Testing and Comparing Sewage Sprinklers. Earle B. Phelps. [*Engineering News*, Volume LVI (1906), pages 410–411. Reprinted, *Technology Quarterly*, Volume XX (1907), pages 34–40.]

4. Studies of Sewage Distributors for Trickling Filters. C.-E. A. Winslow, Earle B. Phelps, C. F. Story, and H. C. McRae. [*Technology Quarterly*, Volume XX (1907), pages 325–374.]

5. The Sterilization of Sewage Filter Effluents. Earle B. Phelps and William T. Carpenter. [*Technology Quarterly*, Volume XIX (1906), pages 382–403.]

6. The Prevention of Stream Pollution by Strawboard Waste. Earle B. Phelps. [United States Geological Survey, *Water-Supply and Irrigation Paper, No. 189* (Washington, 1906). Reprinted, *Technology Quarterly*, Volume XX (1907), pages 292–324.]

7. The Determination of the Organic Nitrogen in Sewage by the Kjeldahl Process: II. Studies on Direct Nesslerization. Leyland Whipple. [*Technology Quarterly*, Volume XX (1907), pages 162–170.]

INTRODUCTION: THE PRESENT STATUS OF THE SEWAGE-DISPOSAL PROBLEM. ACKNOWLEDGMENTS

By WILLIAM T. SEDGWICK, Director

WITH the appearance of a fourth volume of reprinted papers from a Sanitary Research Laboratory and Sewage Experiment Station originally endowed for three years only, the question will naturally be asked, Is the sewage-disposal problem moving towards a final solution? Or is this problem, like the problems of the origin of life, of the antiquity of man, of the age of the earth, and of the constitution of matter, simply another will-o'-the-wisp which recedes as fast and as certainly as it is approached?

To this question we may reply that the investigations of the last few years enable us to affirm without hesitation that real progress has actually been made, and practical results of far-reaching and permanent importance have already been reached; for whereas twenty-five years ago very little was known either about the nature of sewage or about its purification, and sewage-disposal was almost everywhere a purely empirical process, we have now reached a point where any community can deal with its sewage in at least one of several ways, according to its needs, and dispose of it at a reasonable cost; and this, too, without discharging upon the territory of its neighbors or into harbors, estuaries or other water courses more than a minimum of objectionable polluting materials.

The opening paper of Volume II (1905) of the present series consisted of a minute and careful survey by Professors Winslow and Phelps of all that had hitherto been done establishing or tending to establish upon a scientific foundation the theory and practice of sanitary and economical sewage-disposal. A large mass of material was digested, important conclusions were drawn as to the worth or worthlessness of various procedures, and some of the paths were indicated along which new and promising investigations needed to be made. No evidence was found of any tendency towards new difficulties in the way of sewage purification due to unforeseen characteristics of the municipal sewages of American cities, and no changes of condition of sewage in general, excepting those due to increasing concentration or arising from the wastes of special industries in particular places. The sewages of different cities, even in one State, differ indeed to an important extent, but yet as a rule not so widely as to affect qualitatively the methods available for their purification.

Since that time increasing experience has only confirmed and strengthened the same conclusion. Civilization advances after all but slowly; customs tend to become fixed and crystallized, and the sewages of cities, excepting as regards concentration, show no great or fundamental progressive changes in chemical, physical, or biological characteristics. Here clearly is no will-o'-the-wisp eluding our grasp because receding as we draw near, but on the contrary a problem which, as cities grow and industries become established and customs settled, tends everywhere to become more and more similar.

On the other hand and at the other end, the achievements of the last quarter century, and especially of the last few years, in the science and art of sewage purification prove that remarkable progress has been made towards a complete and permanent mastery of the municipal sewage-disposal problem.

Reduced to its lowest terms this problem is simply: *how economically, and without entailing greater nuisances, to make unobjectionable infected streams of fluid filth.* Some elements of this perhaps seemingly simple problem were not at the outset sufficiently attended to, and counter difficulties arose, as, for example, in the method of disposal by chemical precipitation, by which process the sewage nuisance was partly overcome, but to a great extent replaced by the sludge nuisance. Under chemical precipitation streams of sewage discharged by municipalities were rendered comparatively unobjectionable to sight and smell, but the infections which they bore were not removed and a new and serious sludge nuisance was created. Again, intermittent filtration, which in many cases is still the best method of disposal, is for very large cities often uneconomical and impracticable because of its requirement of immense land areas of a special sandy or porous character.

As time has gone on it has gradually become more and more plain that the ideal sewage purification would be one which, while converting the filth borne by the stream into unobjectionable substances, should still keep these substances in solution or suspension, so that they should pass away with the stream and entail no nuisance from deposits; this change, of course, being effected at a tolerable and if possible at a small cost. These conditions the "trickling" or "percolating" or "sprinkling" filtration system promises better than any hitherto devised to fulfill. By this system the filth of a sewage stream is not largely deposited, or even removed, but only changed; so that, although in substance mostly retained, it is in character rendered unobjectionable.

But even this system fails in one important particular, namely, as regards disease germs. Trickling filters do not with any certainty remove disease germs, always possibly present in a sewage stream; and for this reason it becomes necessary in many cases to disinfect somehow the effluents of such filters. That such disinfection can be done without serious difficulty and at reasonable cost has been established by tests made at the Experiment Station of the Massachusetts Institute of Technology, and described in some of the papers contained in the present volume. The experiments here detailed, as well as those made by other investigators elsewhere, make it clear, moreover, that such disinfection can be done if required not only effectively, but also cheaply; as, for example, by the addition of a simple solution of bleaching powder.

These two processes then, namely, the transformation of the organic matters of sewage capable of decay into substances which will not readily rot, and the destruction of disease germs, are thus brought about, — the former by the utilization of a purely natural process, and the latter by simple, artificial means.

But in order to learn how to use these processes advantageously and economically, careful and extended experiments are still required both in general and sometimes also for particular sewages in particular places. The papers which follow describe such experimentation, of which the results already reached are highly satisfactory and encouraging.

By the continued generosity of the public-spirited Donor to whose munificence we are already so greatly indebted, further experiments are already well under way having for their end the ascertainment of the remaining practical data; and the next volume of the present series of "Contributions" will contain an account of such experiments, covering another year's work.

The staff of the Laboratory and Experiment Station remains, happily, unchanged, so that continuity of operation and long familiarity [illegible] problems involved, as well as scientific sequence in [illegible] are insured.

[illegible] credit accrues from all these investigations belongs, first, [illegible] who has incited and steadfastly supported them; sec-[illegible] Massachusetts Institute of Technology, which has administered them; and last, but not least, to Professors Winslow [illegible] means of whose personal devotion and technical skill [illegible] wisely planned and patiently executed.

DISPOSAL OF SEWAGE

BY

PROF. C. E. A. WINSLOW

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
BOSTON, MASS.

Paper read at the Ninth Annual School for
Instruction of Health Officers

Burlington, Vt., June 19, 1907

DISPOSAL OF SEWAGE.

By Prof. C. E. A. Winslow, Massachusetts Institute of Technology,
Boston, Mass.

I feel it a great privilege to address this School of Instruction for Health Officers. Vermont was the first state in the Union to inaugurate such an institution, and I think the step taken in the formation of your School and the success with which its sessions have been attended, has already influenced in a marked degree the progress of sanitary work all over the country. A number of states have followed you in this matter. Schools similar to yours have been held with special success in Ohio and New Jersey, and I look forward to the time when all of our states will be able to testify to the same experience.

The one object which binds us all together, whether we are working in the chemical or bacteriological laboratory, or in the office of the designing engineer, or as local health officers, is the prevention of transmissible disease. Such diseases proceed always from infected persons to susceptible victims by paths which may be quite direct or most circuitous. In all cases our common task is to break the chain of contact at some vulnerable point; and in many diseases, notably those of the alimentary tract, two such points offer especial opportunities for the attack of the sanitarian. These are the points at which infection leaves the body of the sick person and enters the body of the well one. Between these two definite episodes the history of the disease germ in the environment is a various and uncertain one; but excreta may be disposed of, and food supplies guarded from pollution, with reasonable assurance of success.

Efficient protection at both ends of the chain is essential in order properly to safeguard the community. Dr. Darlington eloquently pictured to us last night the dangers which surround the milk supply of the city and showed how essential it is that milk should be produced under cleanly conditions. Yet even after every precaution has been taken, milk when it at last reaches the consumer, must be pasteurized if we would be absolutely certain of its safety. So with regard to water, it used to be said that an unpolluted supply was preferable to a filtered one because "innocence is better than repentance." We have come round to-day to a pessimistic belief in the well-nigh total depravity of water supplies,—from surface sources at least. Sanitarians hold, as Mr. Fuller said yesterday afternoon, that all surface supplies without exception should be purified, yet the obligation to keep them as innocent as possible, before the day of repentance arrives, is none the less imperative. A polluted stream is harder to purify, it is an esthetic nuisance and an economic blunder; and it is *per se* and outside of its relation to water supplies a menace to the public health.

Sewage disposal is a fundamental necessity because the presence of excreta means the existence of continual facilities for the transmission of disease. It is only necessary to study the statistics of communities, in which sewerage systems have been introduced, comparing typhoid death rates before and after that event, in order to realize how serious this danger is. In Berlin, for example, when a pure water supply was introduced the typhoid death rate dropped, but when a sewerage system followed some years later, another decrease in the death rate occurred almost as striking as the first. The reasons are many why sewerage systems thus diminish typhoid fever. The presence of privy vaults is a constant menace to wells and other private sources of supply; but entirely apart from any form of water pollution there are abundant ways in which infection passes from improperly handled excreta to adjacent food supplies. The experience of the United States army during the Spanish War furnished an impressive object lesson along this line. One out of every five of our volunteer soldiers came down with typhoid fever during the brief campaign, in shocking contrast with the almost perfect immunity secured by the Japanese in their triumphal progress through Manchuria. This national disgrace was directly connected with improper care of excreta as brought out by the study of typhoid incidence on different regiments. In peace, typhoid fever slays its multitudes every year from the same neglect of the same precautions. Flies play an important part in its transmission as they forage back and forth from vault to larder; and the fingers of the users of unclean privies are rich sources of infection for themselves and others. These are unpleasant truths, but I have no doubt that citizens of the towns you represent are to-day in the position of the bird that fouls its own nest, without being unconscious of the fact, and it is your duty to awake them to the truth, however unsavory it may be.

The first step in the campaign against typhoid fever is to secure a public source of pure and wholesome water, thus guarding that food supply which most easily carries infection to large numbers of persons. The second step, only less urgent than the first, is to so care for excreta that infection may not be spread broadcast through various other channels. In many communities this must be done by substituting for leaky, ramshackle privies earth closets of adequate construction. To prevent danger, it is necessary that excreta should be received in some receptacle which is water tight and closed against flies. Earth or ashes should be at hand to cover them at once, and provision must be made for burning or burying the contents at frequent intervals. Light and light's brother—cleanliness—are of course essential in the privy building itself.

The proper maintenance of such earth closets is unquestionably a burden, and anything less than this is a public danger. The cesspool, too, which marks the next step forward, is, after all, only a makeshift, since the average citizen has neither the inclination nor the ability to ensure its proper operation. As soon as possible, therefore, the introduction of a water carriage system of sewerage must follow with the growth of the sanitary conscience. This is the ideal method of disposal for the householder, since it removes all excretal matter promptly and efficiently and meets, without trouble on his part, all sanitary and esthetic requirements. It creates, of course, a new problem for the community as a whole; and it is of this problem that I wish chiefly to speak to you this morning. By the construction of a public sewerage system the problem of disposal is shifted one step away from the individual; instead of the individual having a small amount of waste to dispose of, the municipality has now a much larger problem on its hands—the disposal of all waste materials diluted with a great volume of water. For example, in Boston, on one side of the city, known as the South Metropolitan District, it is necessary in every year to dispose in some way of 1,600 tons of nitrogen as free ammonia alone, representing an enormous quantity of organic matter; and the problem is made so much more difficult by reason of the fact that the organic matter is diluted with thirty billion gallons of water.

In American sewages we find only one part in 1,000 of solid matter; in other words, there are 999 parts of water to be handled, or somewhat more than that, for every part of solid matter. The dangerous elements making up the single part in 1,000 with which we are particularly concerned in sewage disposal may be classed under three heads; organic matter, mineral matter and bacteria. The mineral matter is harmful only under exceptional conditions, when large amounts of industrial wastes enter the sewers and need not be considered here. The bacteria are harmful when the sewage is so discharged as to reach some source of food or water supply. The organic matter is harmful when it decays, and creates a nuisance which may be so serious as to menace health. Such organic matter is composed of unstable molecules, imperfectly oxidized, the history of which may follow two different lines. On the one hand, if it remains out of contact with the air, it may decompose, putrefy, break down, with the production of offensive gases of decomposition. Or, secondly, under the influence of oxygen it may undergo another process that we call nitrification, a slow burning or combustion which converts the organic matter into nitrates, or other mineral substances, without the production of foul odors, and in a wholly satisfactory way. Organic matter must either putrefy or nitrify, and the aim of sewage treatment is to nitrify it. This is a difficult problem, because it involves the supply to that organic matter of one to three times its weight of oxygen, with the special conditions under which the oxygen and the organic matter will unite.

The most obvious way to dispose of sewage is to throw it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest water source, and when these drains became filled with polluting matter the same plan was followed. Sometimes this works very well. If the volume of sewage discharged into a stream is sufficiently small, there may be enough oxygen to unite with the organic matter and enough organic life in the stream to effect the union. Under such condition there results a self-purification of a very satisfactory type, as far as the chemical constituents are concerned. Disease bacteria on the other hand, although they do die out in water, decrease slowly and uncertainly, so that bacterial self-purification cannot be relied on to make polluted water potable. Even chemical self-purification has its rather narrow limits. The fate of the sewage changes entirely when its volume exceeds the maximum which may be absorbed by a given stream, roughly stated as one part of sewage to fifty parts of water. When that limit is exceeded, when the limit of available oxygen for the oxidation of organic matter is passed, then the conditions of putrefaction are set up. It is like Mr. Micawber's philosophy: "Annual income twenty pounds, annual expenditures nineteen ought and six, result happiness. Annual income twenty pounds, annual expenditures twenty pounds ought and six, result misery." Up to a certain point everything goes well, but beyond that point, conditions are totally changed and instead of a self-purifying stream you find a foul septic tank. Dilution then—the discharge of sewage into water—is limited by the volume of sewage in relation to the body of water into which it is to discharge. On the seacoast the conditions for purification by dilution are ideal; and with large rivers like the Mississippi this method may be followed very satisfactorily. In smaller streams we get the septic tank condition of which I have spoken. In Massachusetts alone there are at least seven rivers so polluted as to become a public nuisance for a part of their course. Most serious of all, when such a condition as this is reached, there is often so deep a deposit of decomposing sludge in the bed of the stream that after the removal of all fresh pollution it remains as foul and unsightly as before. Nothing but expensive dredging operations will suffice to restore a stream so desecrated to its pristine purity. I beg you to take warning from our more thickly settled commonwealth and avoid while you may such problems as we now find before us in the Neponset and the Blackstone rivers.

A second obvious method of sewage disposal is discharge on the surface of the soil; and this plan has been followed from time immemorial. In the little city of Bunzlau in Prussia there was a public water supply as early as 1559, piped from a spring, and in connection with it was installed a sewerage system and a system of disposal on a sewage farm. Later the process of treatment on land underwent development along more intensive lines. As early as 1865 the German engineer, Mueller, urged the disposal of sewage through land at a more rapid rate than is possible on the ordinary sewage farm. He understood the nature of the process and knew that it was carried out by organic life; and in 1878 he patented a system "for the disinfection, purification and utilization of sewage by the scientific cultivation of yeast-like organisms." In 1870 the subject was approached along a different line by the English experts of the Rivers Pollution Commission under the leadership of Frankland. These experimenters failed to grasp the biological character of the process, but they understood its chemistry and showed that sewage could be successfully purified by filtration through various soils, at much higher rates than those used on sewage farms. It was only by work in this country, however, that these various lines of investigation were brought together in so conclusive a form that the importance of the process of intermittent filtration through sand was generally understood. The difficulties experienced by Worcester through the pollution by its sewage of the Blackstone River and the proposition to treat the sewage of Boston and the cities lying to the north, on the Saugus marshes, made sewage disposal an urgent question in Massachusetts in the early eighties. As a result of these conditions the Lawrence Experiment Station of the State Board of Health was founded in 1887 for the study of the sewage purification problem. There, under the leadership of Mr. Hiram F. Mills, with the coöperation of Prof. T. M. Drown and Prof. W. T. Sedgwick, were carried out the series of experiments since sightly spoken of as classic. Ten circular cypress tanks seventeen feet in diameter and six feet deep were filled with various filtering materials—sand, gravel, peat, river salt, loam, garden soil, and clay. The fine materials like peat, garden soil, and clay soon clogged, but the beds of sand worked to admiration, receiving sewage above and yielding a clear, bright spring water below. Some of the original tanks have been operated from the day of their installation to the present, a period of over seventeen years, with continuously good results.

The Massachusetts investigators established very clearly that the purification was an oxidizing process, carried out by bacteria living in the sand, and that a rich supply of oxygen was necessary for their activity. In order to supply the oxygen it was necessary to dose the filters intermittently, putting on perhaps one dose a day in an amount of some 60,000 gallons per acre. These experiments led at once to the installation of a number of intermittent sewage filters in Massachusetts, and in 1903 twenty-three were in operation in different parts of the state, the best known being those at Marlboro, Brockton, Framingham, Gardner, and Clinton; some of them have been in operation now for over ten years. Where glacial drift sand or lake or river sand is available, the construction of such filters is extremely simple. It is necessary only to remove the soil and subsoil, which may be used for embankments between the individual beds; to dig up the sand at intervals for the laying of underdrains to carry off the effluent; and to level the surface of the beds again and place upon them some simple form of wooden carrier to secure a fairly even distribution of the sewage. Some arrangement must also be made for discharging the sewage on the beds, one dose of 50,000 gallons, the sewage of 500 persons, or two doses of half this amount being applied to each bed once in twenty-four hours. This may be done by hand or accomplished by one of a number of very satisfactory automatic devices now on the market.

In the operation of such beds it has been found that a certain amount of solid material accumulates on the surface, but this sledge is of a stable nature, not subject to decay, and can be scraped off at intervals and removed without excessive expense. Cold winter weather interferes somewhat with the efficiency of the process; but by ridging the beds so that the sewage may flow in furrows under the ice, it is possible with most of the filters in Massachusetts to treat the sewage all the year round.

In districts where it is difficult to secure adequate natural sand beds and where the construction of artificial ones would prove expensive, it is important to increase the rate at which sewage may be purified, and this may be done by the combination with intermittent filtration of preliminary treatment in the septic tank. This device is the logical development of the cesspool and the fosses fixées, used in France by Mouras as early as 1860. The principle that the storing of sewage without access of air led to a sort of fermentation, or ripening, which removed a considerable portion of the solid material--was patented in 1882. Scott-Moncrieff an English engineer, in 1891 used the same process in what he called a cultivation tank, and in 1894 one was installed at Urbana, Ill., by Professor Talbot. The process did not attain wide popularity, however, until after 1895, when Donald Cameron of Exeter, England, gave it the picturesque name of the septic tank. It must be remembered that this scientifically controlled cesspool, as it really is, does not purify the sewage in any real sense. Only oxidation does that, and oxidation requires air. This anerobic fermentation (fermentation without air) serves simply to change solid material to the liquid or gaseous form and thus facilitates its ultimate purification and makes it possible to treat more sewage on an acre of land. Cameron in his early experiments used a tightly closed tank, but he soon found that this was needless; it was only necessary to allow the liquid to flow slowly through any tank, so as to have a storage of about twenty-four hours, the exact length of time varying with different sewages. Under such conditions decompositions take place, which remove from 60 to 70 per cent of the suspended solids, turning a part into liquid form, giving off a part as gas, about 7½ gallons of gas to 100 gallons of sewage, and storing a certain amount of solids in the tank. The proportion of the solids destroyed in the tank digested, so to speak—varies with different sewages and with the same sewage, at different times, under conditions not thoroughly understood. In some cases the use of a septic tank is much more advantageous than in others. Small towns, however, where the sewage arrives in a comparatively fresh condition at the disposal area, will almost always find it beneficial.

The septic tank and the intermittent filter will generally form the most suitable combination for treating the sewage of a New England town. For small communities or institutions or large isolated country houses a modification of this process may be used which obviates the discharge of sewage upon the surface of the ground—an important esthetic factor under some conditions. This is the method of sub-surface irrigation in which the effluent from the septic tank is discharged through a system of open-jointed tile pipe laid a few inches below the surface of a sandy soil. The principle is the same as that of intermittent filtration. Since the sewage is not in free contact with the air, the process of nitrification is more imperfect and the pipes are liable to clog. In many cases, however, the freedom from the somewhat unsightly surface disposal area outweighs these objections. For small installations a plant of this type may be built very cheaply indeed. Mr. John W. Alvord of Chicago has designed such a plant consisting of a barrel for a septic tank, a half barrel equipped with a simple siphon for discharging the intermittent dose, and a system of tile drainage, all under ground, and costing for labor and materials less than twenty-five dollars.

In rocky and clayey districts even the addition of the septic tank will not serve to bring processes of purification through sand within reasonable limits of cost. In England, particularly, the problem has pressed hard; and there progress has been made along a different line. The chemist of the London County Council, Mr. W. J. Dibdin, undertook in the early nineties to devise some more rapid method of sewage disposal than that worked out at Lawrence. He increased the rate by the use of coarse material, following out the principle that the essential element in purification is not really filtration, but the action of micro-organisms which will grow on broken stone as well as on sand. With such coarse material, the sewage must somehow be retained sufficiently long for the bacteria to act on it, and this end Dibdin attained by making his bed (filled with coke) tight, so that he could fill it with sewage, allow it to stand for a certain period and then empty it. This he called the contact system because the sewage is held in contact with the coke by the closing of the outlet. In further experiments at Sutton in Surrey, Dibdin developed the double contact system, carrying the sewage treated in one contact bed to another contact bed and treating it again. By each contact about half the impurities in the applied liquid are removed. It has been found that in the construction of the contact beds almost any hard, smooth material may be used, the bed being simply a tight box for holding it. Coal and coke are particularly favorable, though stone or almost any other hard substance may be used. The size of the pieces of material, whatever it may be, varies from ⅛ of an inch to 1½ inches. The beds are commonly made from three to six feet deep, or thereabouts, but the depth does not seem to be of great importance. The sewage is run slowly into the bed, allowed to stand for a certain time, generally two hours, and then discharged, three or four fillings being made in the twenty-four hours. With such a system sewage may be treated at five or ten times the rate attainable by sand filtration and the effluent, though never purified to the grade of a good spring water, as the effluent from an intermittent filter may be, is so stable that it will not decay and may be discharged into a river with safety.

A still more satisfactory method by which sewage may be treated at even higher rates is the process of trickling filtration, also devised in England. This process secures the necessary even distribution and aeration by sprink-

407526

ing the sewage over the whole surface of the filter bed in a fine spray, so that the oxygen goes in along with it, the sewage never filling the tank, but continuously trickling through the filtering material. One of the advantages of the trickling bed system is the extreme simplicity of its construction. Some kind of floor sloped to carry off the drainage is needed, but aside from this the material used can be held together by wooden palings or iron bands or any very simple structure around the outside. The depth is generally four feet or over, and as in the case of the contact bed, any hard material may be used, varying in size from ⅛ inch to 1½ inches.

A serious difficulty arises in regard to the distribution of the sewage, and it must be so applied as to pass through slowly and well mixed with air. The plans for filters at Columbus, Ohio, like the latest English designs at Birmingham, call for fixed sprinkler heads which throw the sewage up into the air in a fine spray. This device is a good one and may be much improved by the addition of siphon tanks which intermit the discharge at frequent intervals so as to expand and contract the cone of spray and spread the sewage evenly. In the course of our experiments at the Technology Sewage Experiment Station, we have devised another method of distribution which may offer especial advantages in certain cases. This consists of a system of troughs from holes in the bottom of which the sewage drops upon concave discs from which it splashes upward in a fine and well spread spray. This system of gravity distribution was described in the *Engineering News* a year ago and has since been adopted by the Massachusetts State Board of Health for the experimental sewage filter at Amherst.

With good distribution, the rates which may be obtained by the trickling process are very high. The intermittent sand filter will take at the outside 100,000 gallons, and the contact bed 500,000 or 600,000 gallons per acre per day, the trickling filter, on the other hand, easily treats 2,000,000 gallons per acre per days, giving an effluent on the whole better than the contact bed, though not so good as the sand filter. It contains a considerable amount of suspended solids and does not look as clear as the effluent from the contact bed. But it analyzes well and keeps well, which are the principal points to be considered. Furthermore, its solids may be easily removed by a short period of sedimentation.

Returning to the distinction originally made between the chemical and bacterial constituents of sewage, it must be remembered that these rapid processes affect only the organic matter. They are essentially oxidizing mechanisms without filtering action adequate for the removal of microorganisms. It is true that in the unfavorable environment of the septic tank and trickling filter, many sewage organisms do die out, but their elimination is incomplete and uncertain. If a nearly germ-free effluent is desired, as in cases where sewage works are situated upon estuaries where shellfish are cultivated, special means must be taken to remove bacteria. This may be done by chemical treatment, and the development of methods to this end marks the newest step in the growing art of sewage disposal. Chemicals of various sorts were tested most elaborately as precipitants of sewage in the early seventies with poor results. As a purifying process, for the removal of organic matter, chemical treatment is of dubious expediency since the soluble constituents are imperfectly removed and the cost of the process, with its attendant necessity for sludge removal, is generally far greater than the expense of more adequate biological treatment. When organic stability has been attained, however, as in the effluents from rapid processes, chemical treatment may be used with marked success for the purpose of destroying bacteria. Experiments carried out by my colleague, Professor Phelps at the Technology Experiment Station, have demonstrated beyond doubt the cheapness and efficiency of chloride of lime for this particular purpose. Such doses of the chemical as are economically practicable do not destroy all germ life, but they do kill all ordinary sewage and pathogenic organisms, leaving only a few harmless spore formers. The process is not therefore sterilization, but it is disinfection. I am myself inclined to believe that this procedure may not only find application in the treatment of trickling and contact effluents, but in some cases may be used for crude sewage as well. Many towns turn their sewage into lakes or large streams competent to handle for a long time to come all the organic matter which may be discharged into them. In some such cases, the pathogenic germs present do constitute a menace to other communities or to the community chiefly concerned. Disinfection offers a promising method for securing at least temporary relief from such a difficulty.

The particular scheme of treatment to be adopted for any community can only be intelligently selected after a careful study of local conditions. Columbus, Ohio, is the first American city—the Lawrence station being, of course, a state institution—to approach the subject of sewage purification in a rational way. About three years ago the city called in Messrs. Hering and Fuller to investigate and report on the best method of sewage treatment, and appropriated nearly fifty thousand dollars for experimental work. A fine experiment station was equipped in which studies were made of over forty separate methods of disposal. The experts have finally reached the conclusion that the best treatment for Columbus sewage is by the use of the septic tank, followed by the trickling filter, and this again by sedimentation; and they are now proceeding with the construction of the largest plant of this type on our side of the water, including ten acres of trickling filters. Baltimore, Md., is now carrying out investigations of a still more extensive character, along generally similar lines.

The sewage experiment station of the Massachusetts Institute of Technology differs from any other similar testing station in the fact that its scope is wider than a particular local problem. Its purpose, in accord with the wishes of its anonymous founder are to advance the science of sewage disposal in both theoretical and practical aspects and to promote popular knowledge of the nature and importance of this important field of sanitary work. The purely scientific chemical and bacteriological questions involved have naturally claimed a large sphere of our time. We have thought it wise, however, to investigate also the practical problem of the treatment of Boston sewage, now discharged unpurified into the harbor, but likely at some future day to require more careful handling. As at Columbus, the trickling filter seems to offer the best solution of the problem, preceded by septic treatment.

There are many problems still to be solved in the purification of sewage. The removal of suspended matter and its digestion in the septic tank, for example, urgently demand a careful study; yet the work of the last ten years in England and the United States has blocked out the main outlines of satisfactory sewage disposal practice. The engineer can to-day successfully meet any demand for the purification of domestic sewage; and this purification may be carried to any degree of perfection for which the community in question is prepared to pay. If you want a clear and sparkling effluent, highly purified bacterially, he can design you an intermittent filter for that purpose. If you merely want a stable effluent which may be discharged into a stream without creating a nuisance, he can build you a trickling filter. If you want, on the other hand, a disinfected but not organically purified effluent, that end, too, may be attained.

In closing, let me add that what Mr. Fuller said about water purification is equally true of sewage disposal—a badly constructed or badly operated system is worse than none at all, for it creates a false sense of security and blocks the path of true progress. When your community reaches the point when sewage disposal should be attempted, have your local situation studied and your plant carefully designed and place it under conscientious and intelligent supervision. A sewage disposal project so carried out will prove one of the soundest investments any community can make: for its dividends will be paid by the saving of human lives.

[Reprinted from Technology Quarterly, Vol. XX, No. 4, December, 1907]

Contribution from the
Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE IN SEPTIC TANKS AND TRICKLING FILTERS (1905-1907)

By C.-E. A. WINSLOW and EARLE B. PHELPS

I. Results of Previous Investigations

The Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology was founded in 1902 by an anonymous donor for the purpose of making experiments upon improved methods of sewage disposal, especially those adapted to large cities. A large part of the work of the staff has been devoted to the study of the more purely scientific problems — chemical, bacteriological, and hydraulic — which underlie the practice of sewage analysis and sewage purification. We have carried on, however, along with these theoretical investigations, an experimental study of the immediate local problem of sewage disposal, as it is certain some day to confront the city of Boston.

The sewage of the Metropolitan district of Boston is at present discharged, untreated, into the waters of the harbor at three different points. The main outfall sewer of the north district carries some fifty million gallons daily, and discharges continuously off Deer Island. The sewage from the high level district passes out to Peddock's Island, near the southeastern limit of the harbor; this amounts to about twenty million gallons. The main outfall of the south Metropolitan district is at Moon Island, nearer the centre of the harbor, and here the sewage is stored in masonry tanks and discharged only on the turn of the tide. The daily flow in this sewer is in the neighborhood of one hundred million gallons. The Massachusetts State Board of Health investigated the condition of Boston Harbor in 1905 (Goodnough, 1906), and found no serious damage from this method of disposal. The town of Wellesley has, however, recently been refused admittance to the Metropolitan system from fear of overtaxing the purifying power of the harbor (Wellesley, 1907);[1] and it can scarcely be doubted that the progressive increase of population within the drainage district itself will ultimately bring the problem of sewage purification to the fore. The present agitation in regard to the pollution of New York Harbor (Whipple, G. C., 1907) under somewhat similar conditions is an indication of what must some day be expected in Boston.

Under these circumstances it is important to form a general idea beforehand of what a proper purification of Boston sewage will involve; and the investigations at the Sanitary Research Laboratory have reached a point at which this can approximately be determined. It should be understood that neither state nor municipal authorities are responsible for the conclusions which follow. The investigations here reported proceed wholly from the Sewage Experiment Station of the Institute, and deal with a coming problem, not a present one. It is hoped, however, that they may yield data of importance in determining the feasibility of a disposal project when the time for installing one shall come, and offer some guidance as to its probable final form.

The first essential in planning for sewage disposal is a knowledge of the special characteristics of the sewage in question. In a previous communication (Winslow and Phelps, 1905) we have discussed this point somewhat fully. The sewage of the south Metropolitan district, with which we dealt in our experiments, is that which flows from the combined system of the city of Boston proper. It is a typical American domestic sewage, of average strength, and in 1903 morning samples showed an average of about six parts per million of nitrogen as albuminoid ammonia, eighteen parts of nitrogen as free ammonia, and forty-five parts of "oxygen consumed." Suspended solids were at this time somewhat under 150 parts per million. We have pointed out in the paper above cited that the average analysis of the whole twenty-four hours' flow was about 80 per cent. as strong as the morning sewage.

A preliminary series of investigations covering the various methods of purification in common use was carried out from 1903 to 1905. Septic tanks, contact beds, sand filters, and trickling filters were studied, each unit being a cypress tank of 72 to 96 cubic feet capacity, and the results have been fully presented in a previous communication

---

[1] It is understood that this action was taken in view of the fact that Wellesley lies outside the area previously fixed upon as properly tributary to the Boston outfall.

(Winslow and Phelps, 1906). These studies led to certain general conclusions which may be summarized as follows:

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 16,000 pounds (.65 cubic yard) per million gallons of sewage, and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected, if desired, by treatment in the septic tank. In our experiments an open tank operated as well as a closed tank. Varying the storage period from twelve to forty-eight hours produced no difference in the effluents which was measurable by analytical results. The tanks studied removed nearly two-thirds of the suspended matter and yielded an effluent which was clear, but much darkened by sulphides. The tanks on an average received fifty pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which thirty pounds were discharged in the effluent, fifteen to seventeen pounds decomposed, and three to five pounds stored as sludge. In the decomposition of sludge the length of the septic period was of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed was twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments, crude Boston sewage was successfully filtered through a 2-foot bed of sand with an effective size of .14 mm., at a rate of .4 million gallons (400,000 gallons) per acre per day, divided into four doses in the twenty-four hours. Such high rates should not be expected in actual practice, with outdoor beds, particularly during the winter months. In communities with limited sand areas much might be accomplished, however, by frequent cleaning of the surface of the beds; and it is interesting to know that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds in these experiments were clear, bright, and well purified. Preliminary septic treatment for twelve or twenty-four hours did not improve the effluents obtained with sand filtration, although it made the care of the surface of the beds somewhat easier.

It was found that crude Boston sewage could be treated in single-contact beds of fine stone (½ inch in diameter) at a rate of about

1.2 million gallons per acre per day. The effluent, though only partially purified, was generally so stable that it could be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clogged rapidly and the surface needed much attention. The double-contact system of treatment, in primary beds of 2-inch material and secondary beds of ½-inch material, yielded a fairly well purified and stable effluent at a rate, on the combined double system, of about 0.7 million gallons per acre per day, with beds 6 feet deep. This system clogged much less seriously, but nevertheless lost sufficient capacity to require renewal every few years. Preliminary septic treatment obviated this loss of capacity to a considerable extent.

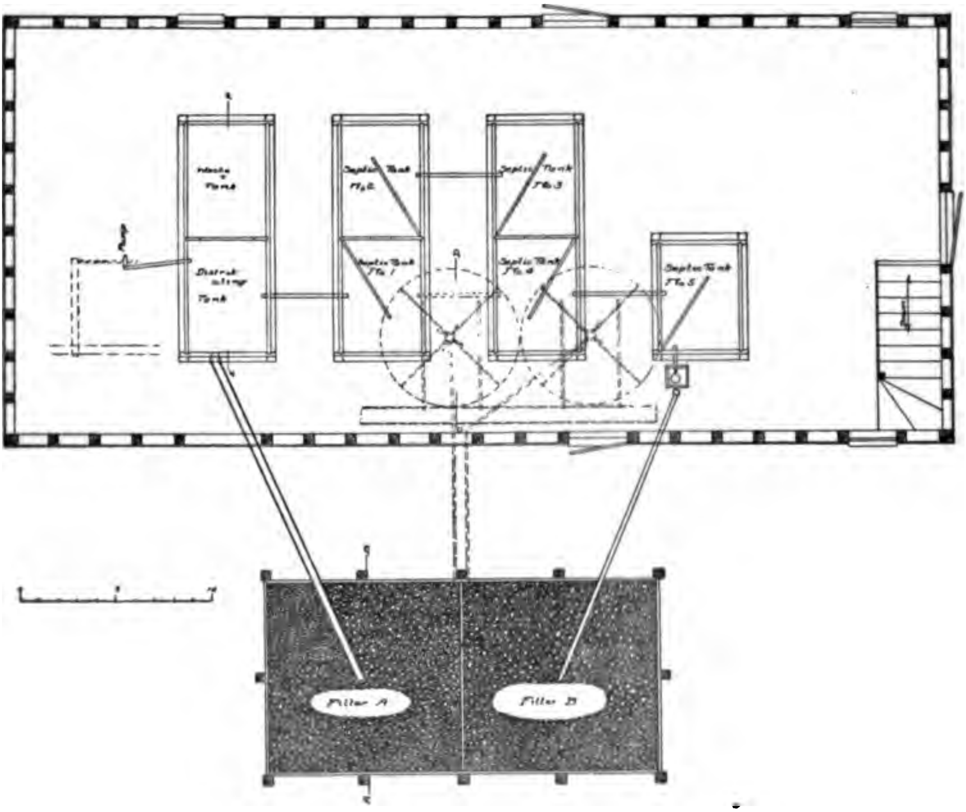


FIG. 1.—PLAN OF EXPERIMENTAL PLANT

Experiments with continuous, trickling, or sprinkling filters showed results equal to those obtained with the double-contact system at much higher rates, and suggested that this method would probably prove the most practical of all. Three such tanks were studied, one from 1903 on and the other two in 1904 and 1905. They were operated at rates between 1.5 and 2.5 million gallons per acre, producing turbid but fairly stable effluents, and were entirely free from surface clogging. To base conclusions as to the efficiency of trickling filters upon tanks only 16 square feet in area, dosed with tipping buckets and operated under cover, seemed, however, unwise. For such a general survey as was contemplated in our preliminary work, and particularly for studies of contact beds, small indoor filters are of value; but the two important points in the operation of the trickling filter are the system of distribution and the effect of winter conditions, neither of which can be studied on a small scale. We therefore constructed in August, 1905, an outdoor filter of adequate size, which has been successfully operated for nearly two years; this has yielded results which we believe to be representative.

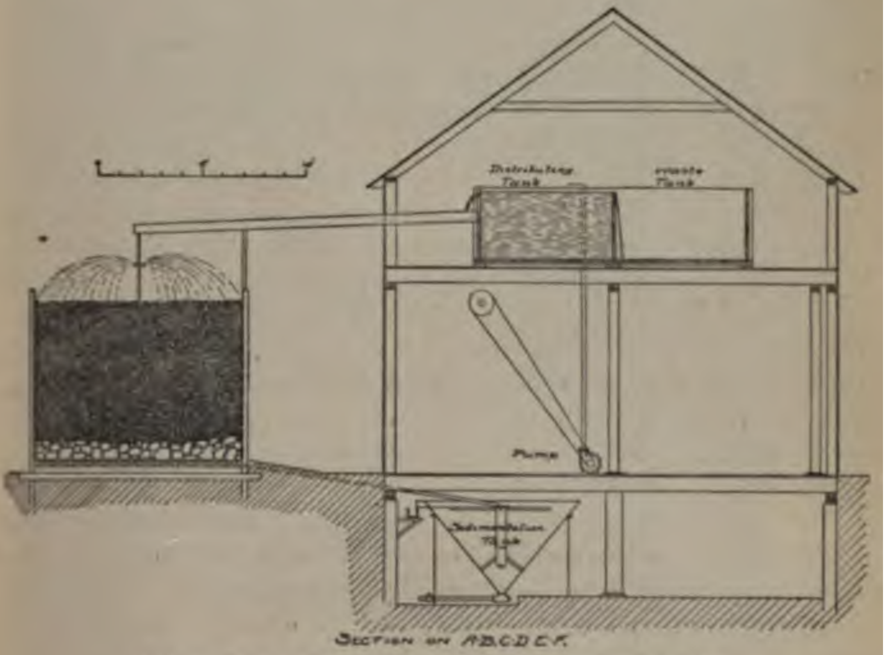


FIG. 2.—SECTIONAL ELEVATION OF EXPERIMENTAL PLANT

II. DESCRIPTION OF THE EXPERIMENTAL PLANT

The Sewage Experiment Station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany Street and Massachusetts Avenue. It includes a small, two-story laboratory building, a two-story tank house, and the trickling filter. Septic tanks and sedimentation basins are placed inside the tank house. The general arrangement of the tank house and filter is shown in Figures 1 and 2.

Sewage for the use of the station is obtained from the 9-foot trunk sewer of the Boston Main Drainage Works at a point where there is a flow of some fifty million gallons a day from a contributing population of 250,000. It is raised by a 4 × 6 Warren duplex pump, being roughly settled on the way by passage through a grit chamber, 19 inches in diameter and 16 inches deep, fitted with a screen whose bars are ½ inch apart. The sewage is then raised, without further sedimentation, by a ¾-inch centrifugal pump to the distributing tank, shown in the plan and section, Figures 1 and 2 No sludge was removed from this tank, and the inflow was kept always in excess of the outflow, a constant head being maintained by wasting over a 36-inch weir at one end. From the opposite end of the distributing tank sewage flowed to one of the trickling beds, filter A, over a 1-inch brass weir, the crest of which could be raised or lowered by a micrometer screw. By regulation of this crest in relation to the constant height on the waste weir it was possible to obtain any desired flow on the filters. A depth of about 1 inch on the small weir corresponded to 200 gallons per hour, or 2,000,000 gallons per acre per day, the rate in use for the past two years.

From one side of the distributing tank sewage flowed continuously through a short length of 2½-inch iron pipe to the first of the septic tanks. These were open cypress tanks, 6 × 4 feet × 3 feet deep, connected in series by 2½-inch iron pipe.

The general arrangement of the septic tanks is indicated in Figure 1. Only Nos. 1, 4, and 5 were used during the first twelve months of the investigation. In October, 1906, the direct connection between 1 and 4, and 4 and 5, was cut off and Nos. 2 and 3 brought into the series. The distributing tank and all five septic tanks have since that time been in open connection, the level in all being controlled by the large waste weir of the distributing tank. The septic tanks were provided with wooden baffles, arranged as shown in Figure 1. The total capacity of the septic system was equal to twelve hours' flow, and its division into five separate tanks made it possible to study successive stages in the septic process. From the last tank, a 1-inch brass weir, exactly like that on the distributing tank, regulated the flow on the second trickling bed, filter B.

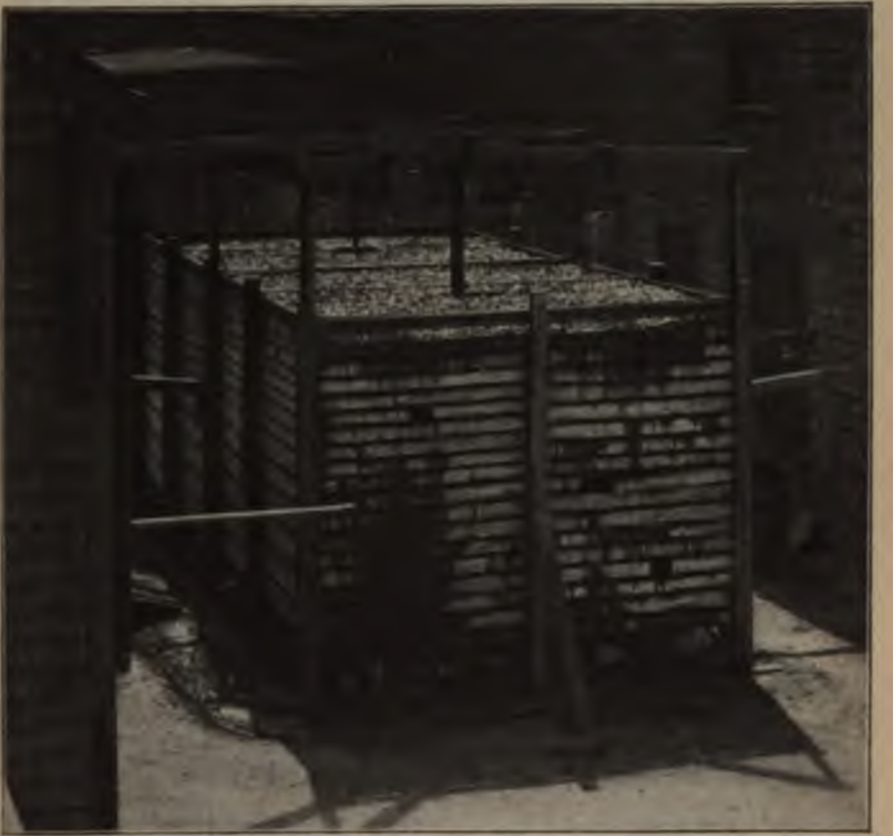


FIG. 3.—VIEW OF EXPERIMENTAL TRICKLING BEDS

A general view of the trickling beds is shown in Figure 3. The combined superficial area of both beds was 200 square feet, and the depth 8 feet. A central partition of 2-inch spruce planking, with matched joints, divided the total area into two separate beds, each 10 feet square. Filter A treated crude sewage and filter B septic effluent. Both beds were filled with crushed stone, granite, and trap, between 1½ and 2 inches in diameter.

The construction of the filters was as follows: For a foundation, 4 × 4 inch spruce beams were buried in the ground, with top surfaces flush. A hemlock floor 1 inch thick was next laid and covered with a layer of 1 to 2 Portland cement mortar, 1 inch thick at the inner corner of the filters near the tank house, and sloping up to a thickness of 3 inches at the opposite side. Four radiating channels in the cement, ½ inch deep, aided the flow to the inner corners, from which the effluent was conducted into the tank house by 1½-inch iron pipes, 8 feet long, with a slope of about 1 foot. The sides of the filter (Fig. 3) were of spruce planks, with ½ to 2-inch openings between them, the lower 18 inches being entirely open. These sides were supported by 4 × 4 inch uprights, braced on all sides and tied at the tops by ½-inch iron rods. On the cement floor two layers of brick were laid in open

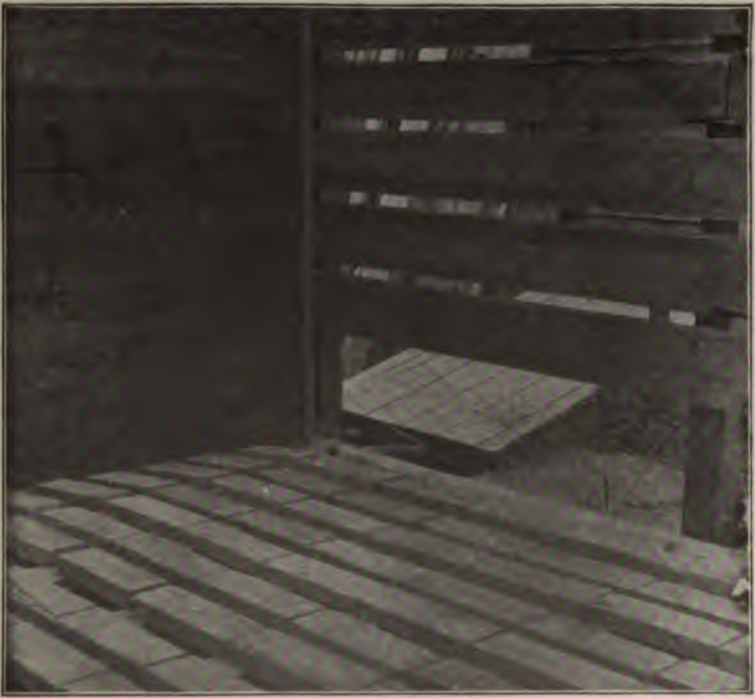


Fig. 4.—Underdrainage System of Trickling Beds

courses, as shown in Figure 4, to ensure good underdrainage. On these were 18 inches of bowlders and 65 inches of the main filling material — 1½ to 2-inch crushed stone.

For spraying sewage over the surface of the filter a new method was devised, which we have called the system of gravity distribution. This was described by us a year ago (Winslow and Phelps, 1906 *b*), and has since been adopted by the Massachusetts State Board of Health for its experimental filter at Andover (Clark, 1907). In this system a fine spray is produced, not by throwing the sewage up into the air from a fixed nozzle, but by discharging it downward from an opening in the bottom of a trough on to a concave metal plate, from which it splashes upward. The plan first adopted allowed four such splashing disks for each of our two filters. During this period the arrangement of the system was as follows:

The sewage from the two dosing weirs, in the distributing tank and in the septic tank No. 5, flowed out from the tank house through open wooden troughs, 3 inches in width and 3 inches deep. From these the sewage dropped into similar troughs, which ran from corner to corner of each of the two filters, joining at the centre in the form of a cross. The sewage passed into this cross at its centre, flowed out into the four arms, and dropped through ¾-inch holes to the disk distributors, four to each bed, 100 square feet in area. In each hole was a 3-inch piece of ¾-inch brass tubing, threaded on its upper inch and screwed to a lock nut inside the trough. Any inequality in distribution due to change in the level of the distributing troughs was easily corrected by changing the position of this short tube. Below the troughs the stream of sewage was protected from the wind by a box extending down for 12 inches, and at 15 inches below the trough the stream struck a shallow concave disk, from which it splashed outward. On the filter, as operated during the first year, these disks were 3 inches in diameter, and their concavity had a 6-inch radius. Each was held in place by four ¼-inch brass rods. The general arrangement of this distribution system is shown in Figure 3. It worked with fair success, breaking up the sewage well, and not requiring an excessive amount of attention. Some difficulty was experienced during the winter of 1905–06, but the beds remained in operation. On the coldest days an umbrella of ice surrounded each disk, somewhat limiting the surface distribution; but within this shield the spray worked well.

With disks spaced in this manner, however, there were considerable intermediate areas of the filter which did not receive sewage, while the portions directly under the disks were operating at excessive rates. During the summer of 1906 pooling occurred on the raw sewage side, and in November of that year we substituted for the four splashing disks

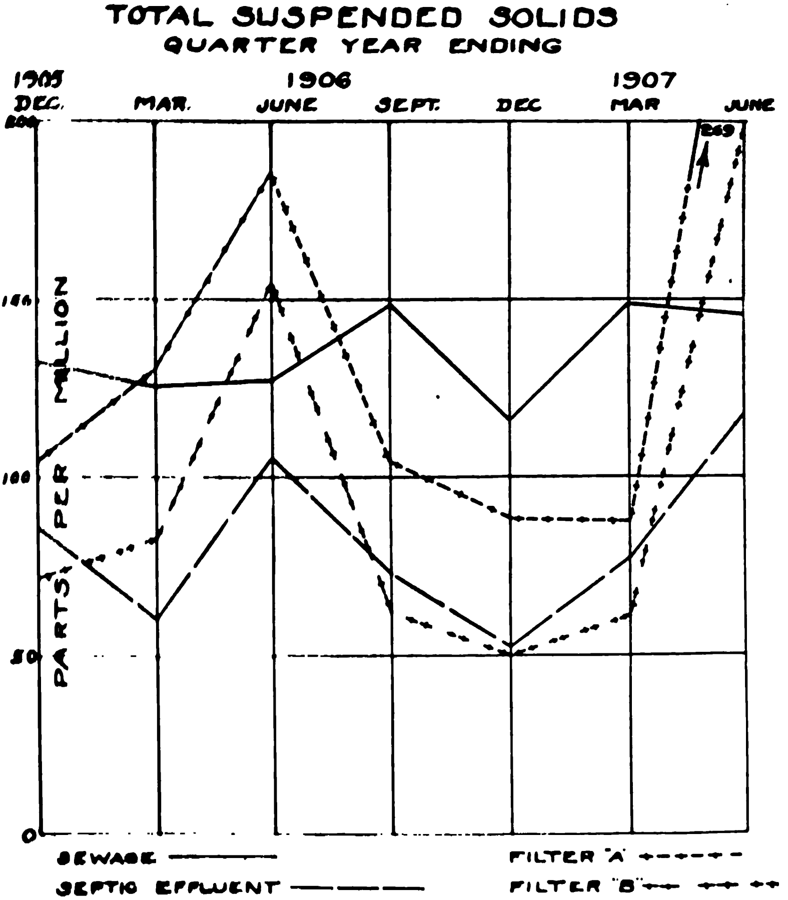


FIG. 5. QUARTERLY VARIATIONS IN TOTAL SUSPENDED SOLIDS; SEWAGE AND EFFLUENTS

on filter A a single splashing disk of the same type, placed at the centre of the square. This single disk, with four times the discharge upon it, gave a much better distribution over the 10-foot square than its four predecessors. A detailed study of the efficiency of various trickling filter distributors (Winslow, Phelps, Story, and McRae, 1907) has shown that this type of splashing disk gives more even distribution than any other device, except certain complicated pressure nozzles with small openings. For purposes of comparison we installed on filter B a pressure nozzle of the type used in the early experiments at Columbus, Ohio. This has "a single orifice, $\frac{9}{16}$ inch in diameter, with rounded edges, above which, held by two thin arms, is an inverted

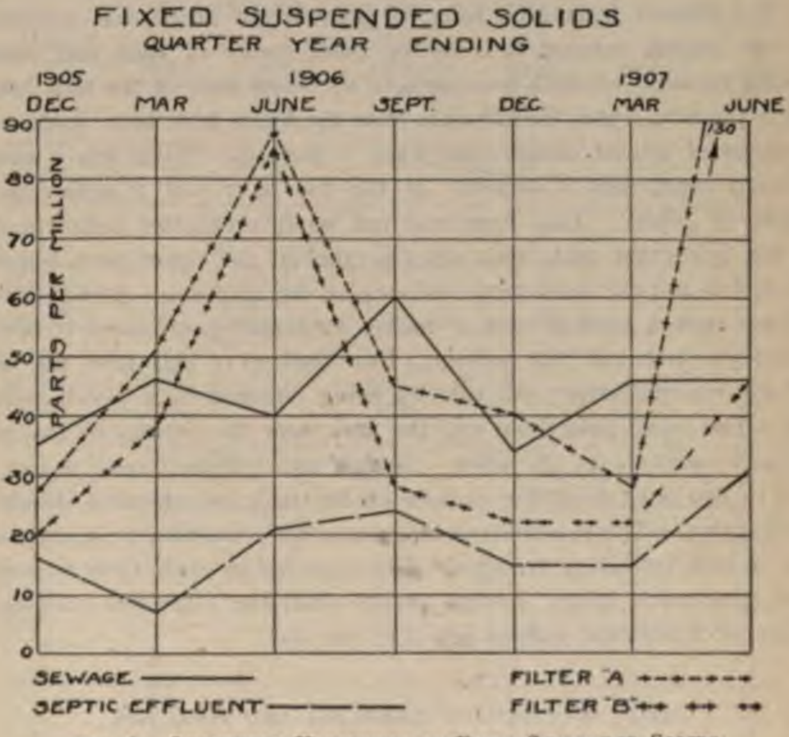


Fig. 6.—Quarterly Variations in Fixed Suspended Solids; Sewage and Effluents

90° cone, the axis of the cone coinciding with the axis of the orifice. The jet on leaving the orifice impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops" (Gregory, 1906).

A nozzle with an orifice as large as that of the Columbus sprinkler, when operated with a 4-foot head, as in our experiments, produces an excessive discharge. We therefore placed a dosing chamber between septic tank 5 and filter B, equipped with an automatic, air-locked siphon, discharging at a head of 4 feet and cutting off at 3 feet. Ball floats operated the air valves, which started and cut off the siphon sharply at the beginning and end of its discharge. In operation, the siphon tank filled in one minute twenty-six seconds, and took one minute ten seconds to empty. It discharged through a 2-inch pipe, which passed into filter B about 6 inches below its surface, rising again at the centre of the bed just above the level of the stones.

The effluent from each filter, as pointed out above, was conducted by the sloping cement floor to the inner corner of each bed, thence flowing through 1½-inch iron pipes to the lower floor of the tank house. Since January, 1906, the effluents from the filters have been sedimented in tanks of special design (see Figs. 2 and 19). Each was a simple inverted cone, with a diameter at the top of 7 feet 2 inches and a height of 4 feet. This form was not so favorable for sedimentation as the Dortmund tank, with sides parallel in the upper part, but was adopted to suit the head room and area at our disposal. At the centre of each tank a vertical tube, 6 inches in diameter, extended to within 1 foot 3½ inches of the bottom. Into the top of this tube the filter effluent was discharged, its velocity being checked by a 3-inch conical cup. The liquid passed out into the tank near the bottom of the tube through openings in its sides. Sludge was removed once a day or once in two days from the bottom of the tank by the valve shown in the diagram. The supernatant liquor rose and overflowed through two 2 × 3 inch collecting troughs. The capacity of each tank was such as to give a two hours' storage period when the filter was running at a rate of 2,000,000 gallons per acre per day.

III. METHODS OF SAMPLING AND ANALYSIS

All chemical examinations were of composite samples. Portions were collected every three hours, day and night, and at once chloroformed; these were mixed and analyzed at the end of each week. One composite sample of the sewage and of each effluent was analyzed each week for the whole period of investigation.

Turbidity and sediment were observed in each sample by the use of the Jackson turbidimeter recalibrated for coarse material (Phelps, 1905). Total and fixed solids were determined by the Gooch crucible method of Kimberly and Hommon (1906).

Total organic nitrogen values were obtained by a modified Kjeldahl method, previously described (Phelps, 1905), and during the last year nesslerizations have been made directly by a method devised by Whipple at this laboratory (Whipple, L., 1907).

Free ammonia was read by direct nesslerization against permanent standards. For nitrates the brucine method was used (Farnsteiner, 1902). "Oxygen consumed" was determined after thirty minutes' heating on the water bath. This determination, and all others not specifically mentioned, were made according to the standard procedure recommended by the Committee of the American Public Health Association (1905).

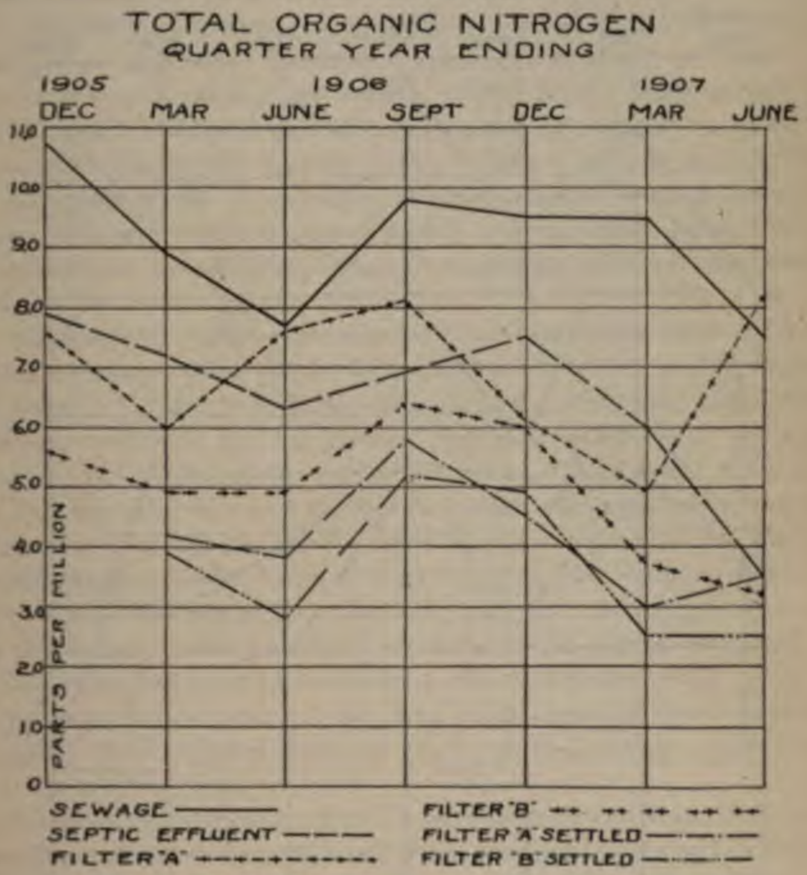


FIG. 7.—QUARTERLY VARIATIONS IN TOTAL ORGANIC NITROGEN; SEWAGE AND EFFLUENTS

Experience with the newer processes of sewage treatment has made it clear that the ordinary methods of analysis are insufficient by themselves to furnish all the information necessary with regard to the character of a sewage effluent. Our knowledge of sewage chemistry has not yet made it possible to discriminate clearly between putrescible organic matter and those more stable "humus-like" compounds which

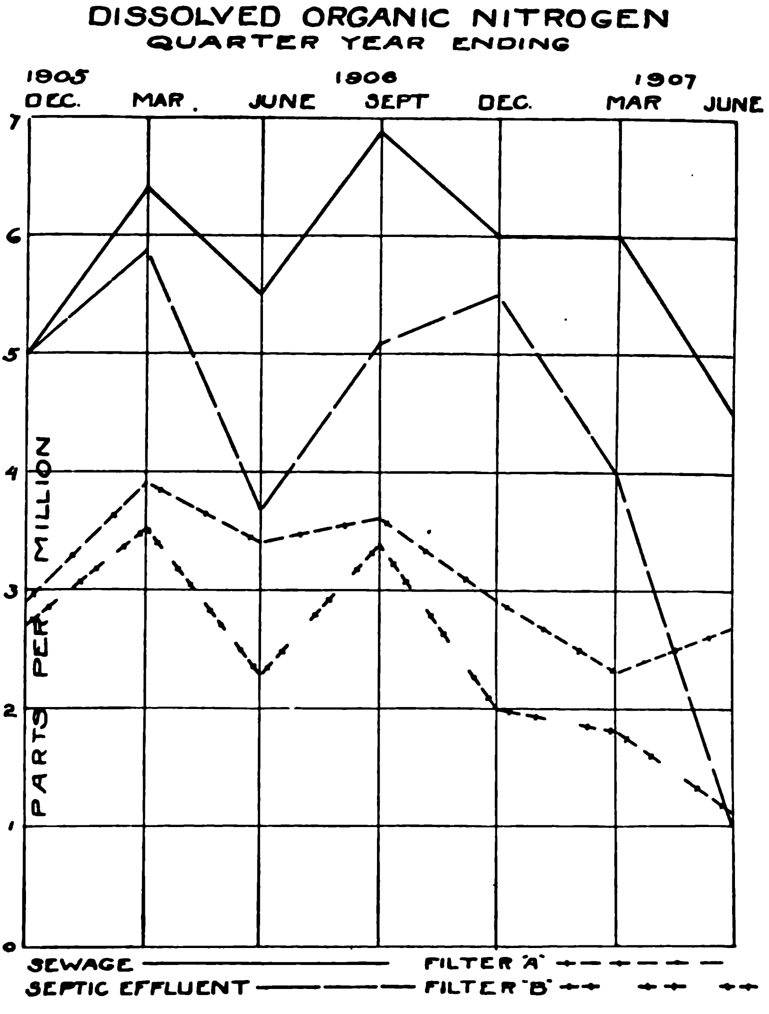


Fig. 8.—Quarterly Variations in Organic Nitrogen in Solution; Sewage and Effluents

do not undergo putrefactive decomposition. With intermittent sand filters, effluents are obtained which contain only a small amount of organic matter of any sort; and the purity of such effluents is easily demonstrable by oxygen consumed and nitrogen determinations. With effluents from contact and trickling filters, on the other hand, the ordinary analytical data do not offer a complete criterion of quality. An effluent may contain a considerable amount of organic nitrogen and give a high value for oxygen consumed, and may yet prove of excellent quality because its organic matter is in a stable form. In such cases it becomes necessary to supplement sanitary analysis by some practical test of keeping quality. Such a test, if its technique is easy, can be made to advantage at more frequent intervals than the more elaborate chemical examinations; and in small plants, where the latter are out of the question, it alone may prove of considerable value.

Although the terms putrescible and non-putrescible stand for quite definite characteristics, yet the separation of effluents of various degrees of purity into these two classes depends to a considerable extent upon the test employed for the purpose, and none of the older tests for stability has proved wholly satisfactory. The "smell test" is inexact, and at the other extreme the determination of oxygen consumed, dissolved oxygen, nitrates, and nitrites is too cumbrous a process for routine work. Furthermore, it does not accurately measure the relation of oxidizable matter to available oxygen, since the oxygen consumed by permanganate bears a variable relation to the organic matter which is oxidizable under natural conditions. The "Manchester test" is somewhat more satisfactory; but this, too, yields abnormal results at times, and only divides effluents into two rough classes, without distinction as to their relative grade.

A new putrescibility test, simple in technique and measuring accurately and delicately the relation between available oxygen and oxidizable matter, has, therefore, been a desideratum. Such a method appears to be at hand in the methylene blue test, first devised by Spitta (1903) for the study of stream pollution, and later more thoroughly worked up by Spitta and Weldert (1906) as a test for sewage effluents. The technique employed is extremely simple. A small portion of an aqueous solution of the dye (in our experiments 1 c.c. of a .1 per cent. solution) is added to the effluent in a glass-stoppered bottle (250 c.c. capacity in our work), and the sample is then incubated either at

20° C. or at 37° C. The blue color of the solution remains practically unchanged during the period of observation until the available oxygen contained is used up and putrefactive conditions arise. At this point the dye is reduced and decolorized. The time required for decolorization is a quantitative measure of the degree of putrescibility of the sample, and the retention of the color for a period of four days or more at 20° C., or of two days at 37° C., may be taken as an indication of good stability. The criticism of Johnson, Copeland, and Kimberly (1906), that "substances other than putrescible organic matters, such as sulphide of iron and hydrogen sulphide," discharge the color of methylene blue before the putrescible matters themselves are able to act, does not

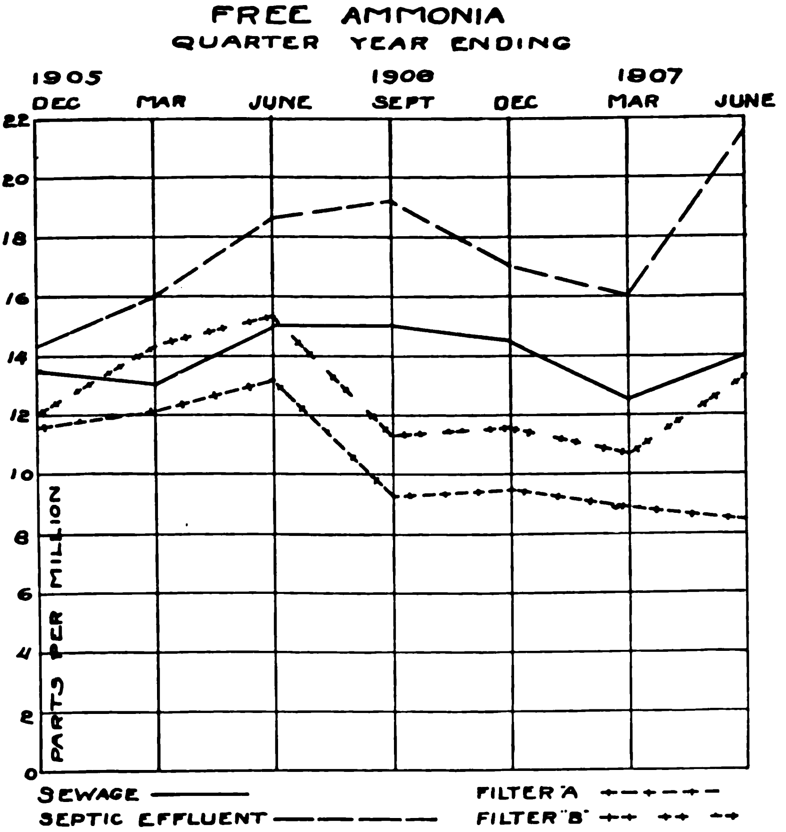


FIG. 9.—QUARTERLY VARIATIONS IN FREE AMMONIA; SEWAGE AND EFFLUENTS

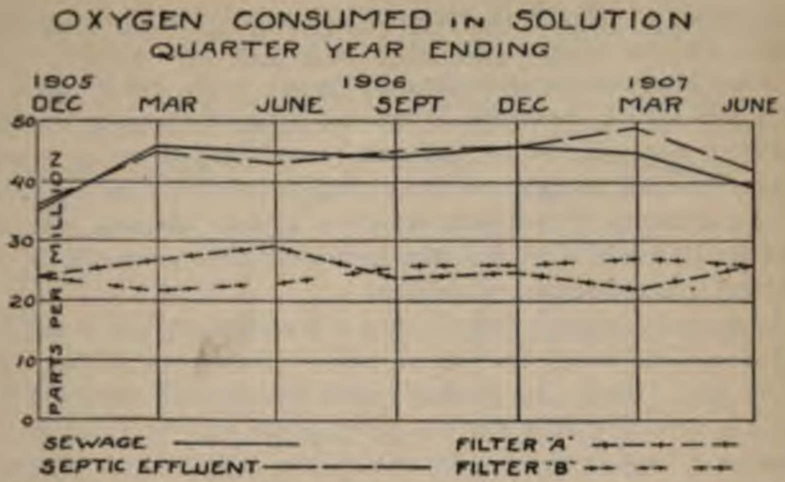


FIG. 10.—QUARTERLY VARIATIONS IN "OXYGEN CONSUMED" IN SOLUTION; SEWAGE AND EFFLUENTS

seem to us well taken, since such substances are present only when the effluent as a whole is in unstable condition.

Spitta and Weldert state that putrefaction occurs from two to four times as fast at 37° as at the ordinary room temperature. We have made a somewhat fuller study of this temperature factor and of some other points in connection with the methylene blue test, which have been reported elsewhere (Phelps and Winslow, 1907). For twenty samples of trickling filter effluents, the decolorization times at 20° and at 37° were determined to the nearest half day, and the ratios of the 20° times to the 37° times are tabulated in Table I. The actual number of days varied from half a day to thirteen days at 37° C.

TABLE I—RATIO OF TIME REQUIRED FOR DECOLORIZATION OF TRICKLING FILTER EFFLUENTS AT 20° TO THAT REQUIRED AT 37° C.

2.5	2.0	1.6	1.6
1.5	2.6	1.0	0.5
2.7	2.0	4.0	2.2
1.8	2.0	2.0	2.3
1.4	1.9	2.4	2.0

With the exception of two very low ratios (.5 and 1) and one high ratio (4), all these figures fall between 1.4 and 2.7, and the average of all is exactly 2. It may be considered, therefore, that methylene blue samples will generally decolorize at 37° in half the time required at 20°.

It must be remembered in interpreting this table, and all others in which comparative decolorization tests are recorded, that each test must be made in a separate bottle; and since the sampling of sewage is never perfect, there will be variations due to chance differences in the several bottles compared. This is particularly true in work like that later cited in Table III, in which decolorization tests were made in one bottle and analytical data determined on another.

In general, it appears from Table I that results obtained at 20° bear to those obtained at 37° the ratio of 2 to 1. Stable samples are stable at any temperature. In grading putrescible samples, however, it is evidently necessary to select one temperature and to use it for all comparative work. The temperature of the body has the advantage that it gives results more promptly. Any sample which does not decolorize in four days is certainly stable, and a two days' limit would include almost all putrescible effluents. The 20° method, however, from the very fact that it is slower, permits a more delicate measurement of the relative differences between putrescible effluents of different grades. Decolorization here may occur from the first up to the fourteenth day. Slight variations from 20° will not introduce a serious error in the test, and diffuse daylight does not appreciably interfere with it. A series of control experiments made in daylight, in a box at the room temperature (in summer), and in an incubator at 20°, are recorded in Table II, and indicate that the test could be made in an ordinary room with fairly controlled temperature. Experiments made during cold weather in a small frame building heated by a stove showed marked abnormalities, on the other hand, and emphasize the fact that temperature variations cannot be allowed to go too far.

TABLE II—EFFECT OF TEMPERATURE AND LIGHT ON METHYLENE BLUE TEST

Average Time of Decolorization in Days

Week ending	Effluent A.			Effluent B.			Effluent C.		
	Summer temperature.		20° dark.	Summer temperature.		20° dark.	Summer temperature.		20° dark.
	Daylight.	Dark.		Daylight.	Dark.		Daylight.	Dark.	
June 27	1	2	2	11	11	7	2	3	3
July 2	3	3	3	12	12	10	3	3	4
July 9	2	2	2	2	3	2	2	3	3
July 16	2	3	2	9	12	10	13	13	13
July 23	2	3	4	7	8	7	14+	14+	14+
July 30	2	5	6	13	14+	13	12	14+	13
August 6	2	3	3	6	6	6	14+	13	13
August 13	3	5	4	13	13	12	13	13	13
August 20	10	5	5	14+	14+	14+	14+	14+	14+

With regard to the significance of the methylene blue test in relation to the specific chemical changes which go on in putrefaction, Spitta and Weldert have little to say, beyond pointing out that decolorization takes place only after all the available oxygen has been exhausted, which point they illustrate by a single experiment. We have studied the relation between decolorization and chemical processes a little more fully, and the results of the examination of five samples of trickling effluents are shown in Table III.

TABLE III—OXYGEN CHANGES IN PUTRESCIBLE TRICKLING FILTER EFFLUENTS

Decolorization of Methylene Blue Indicated by *

(Parts per Million)

Sample.	Days at 37°.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
			Nitrates.	Nitrites.	
1	Initial	8.0	3.0	1.0	5.0
	1*	0.0	0.0	0.3	5.0
	2	. .	. .	0.1	. .
2	Initial	10.0	8.0	1.0	4.0
	1	1.0	3.0	1.0	4.0
	2	0.0	0.0	1.0	3.4
	3	0.0	. .	0.1	4.0
	4	. .	. .	0.08	4.0
	5	. .	. .	0.03	3.8
	7	. .	. .	0.0	4.0
	8	. .	. .	. .	4.8
	9	. .	. .	. .	6.3
3	Initial	8.0	3.5	0.5	6.0
	1	1.0	3.0	1.2	4.8
	2	1.2	3.0	1.4	5.7
	3	0.4	3.0	1.0	5.2
	4	0.0	0.0	0.0	5.0
	7*	. .	. .	. .	. .
4. M. B. sample lost	Initial	10.8	4.0	0.3	4.2
	1	1.8	3.0	0.3	4.5
	2	0.2	3.0	0.5	4.4
	3	0.2	3.0	0.1	3.4
	4	0.6	2.5	0.1	2.5
	5	0.0	1.0	0.1	4.3
	6	. .	0.0	0.06	3.6
	7	. .	0.0	0.0	2.7
5	Initial	9.2	3.0	0.6	5.2
	1	1.2	2.5	0.0	5.3
	2*	0.0	0.0	0.0	5.3
	3	0.0	0.0	0.0	5.7
	4	. .	. .	. .	4.6
	5	. .	. .	. .	3.9
	6	. .	. .	. .	6.1
	7	. .	. .	. .	6.9

It is evident that the free dissolved oxygen is absorbed first by the organic compounds present; then the nitrates disappear, and finally the nitrites; and the methylene blue is generally attacked just after the disappearance of the latter. Sometimes, as in samples 2 and 3, there is a considerable delay between the disappearance of nitrites and the decolorization of the methylene blue. This may probably occur when the organic matter and the available oxygen are about evenly balanced, so that after the exhaustion of the oxygen putrefactive changes are set up somewhat slowly. Whenever the methylene blue is decolorized it may be assumed that all oxygen as nitrates or nitrites has disappeared; and, *vice versa*, when the blue color is retained traces of these bodies are generally present. This condition is illustrated in Table IV for trickling filter effluents which did not decolorize after fourteen days at 37°. It will be noticed that these effluents contained a considerable amount of organic matter as measured by "oxygen consumed," and that in all cases there was a marked reduction in oxygen content during incubation. Nitrites and nitrates remained, however, in all but three cases. This condition may be compared, for contrast, with that of the putrescible effluents in Table III and with four other sets of analyses quoted in Table V.

TABLE IV—OXYGEN AND OXIDIZABLE MATTER IN STABLE TRICKLING FILTER EFFLUENTS

(Parts per Million)

INITIAL COMPOSITION.				AFTER FOURTEEN DAYS AT 37°.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.			Nitrites.	Nitrates.	
6.8	4.0	5.5	5.6	0.0	0.0	0.0	3.2
2.8	3.0	5.5	8.4	0.3	3.5	1.5	7.6
5.2*	0.0	15.0	4.4	4.0	0.1	15.0	4.4
7.2	5.0	3.0	18.8	0.1	0.4	1.5	8.9
4.4	3.0	3.0	5.2	0.0	0.1	1.5	3.5
7.2	4.0	6.0	16.8	0.1	0.5	5.0	15.8
4.6	3.0	6.0	10.4	0.0	1.5	1.0	12.2
4.4	2.5	5.5	9.6	0.0	0.0	0.0	7.0
4.4	3.0	5.5	8.4	0.2	0.8	1.5	2.0
6.6	1.0	2.0	17.4	0.0	3.0	0.1	2.6
4.2	1.5	3.0	7.2	0.0	1.0	0.0	0.6
5.7	2.5	3.0	8.4	0.0	0.0	0.0	5.2
4.3	3.0	4.0	7.0	0.6	6.0	2.0	7.7

* Sand filter effluent.

TABLE V—OXYGEN AND OXIDIZABLE ORGANIC MATTER IN PUTRESCIBLE TRICKLING FILTER EFFLUENTS

(Parts per Million)

INITIAL COMPOSITION				Age, hours at 37°.	AFTER DECOLORIZATION.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.		Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.				Nitrites.	Nitrates.	
4.3	2.0	3.0	24.4	24	0	0	1.5	25.2
1.1	2.5	3.0	14.0	12	0	0	0.0	14.0
5.8	1.5	5.0	15.6	40	0	0	0.0	16.0
3.8	1.5	5.0	8.8	120	0	0	0.0	2.8

An interesting practical question arises as to the relation of the methylene blue test to the original constitution of the effluent as determined by chemical analysis. If our methods were sufficiently precise we should be able to predict from determinations of organic matter and oxygen just what the result of their interaction will be. The condition of an effluent, as indicated by the relation of oxygen consumed to available oxygen, corresponds, however, only roughly to its putrescibility. Comparing Tables III, IV, and V, a general difference between the stable and putrescible samples is apparent, the former, in Table IV, having on the whole a considerably higher ratio of available oxygen to oxygen consumed than the latter, as shown in Tables III and V. There are, however, many samples which contradict this general rule, and we have been unable on any basis of calculation to find a marked and constant difference in analysis between stable and putrescible samples. This has been still more forcibly brought out in our routine experiments. For a considerable period, as will be shown later on, one of our trickling beds gave stable effluents, while those from the other bed were putrefactive. Yet at the same time there were no

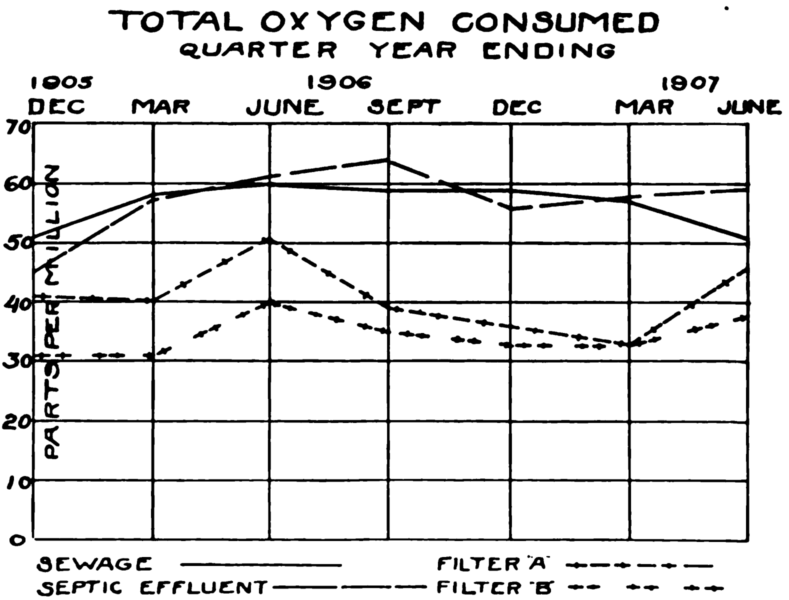


FIG. 11.—QUARTERLY VARIATIONS IN TOTAL "OXYGEN CONSUMED; SEWAGE AND EFFLUENTS

significant differences in the nitrogen and oxygen-consumed values of the two effluents. It is evident that certain factors affect the stability of an effluent which are not revealed by the ordinary methods of sanitary chemistry; and since this property of stability is precisely the point of greatest significance in sewage purification, the methylene blue test seems to us of supreme value in judging the work of trickling filters. We have therefore used it since February, 1906, in all our routine work, making daily tests of crude sewage, septic effluent, and trickling effluents before and after sedimentation.

Bacterial samples of sewage and effluents were taken three times a week from October, 1906, to April, 1907, and counts were made on litmus lactose gelatin at 20°. As a presumptive test for *B. coli* the bile medium of Jackson (1906) was used. As in Jackson's work, natural ox-bile was used, with the addition of 1 per cent. lactose; but we incubated our tubes for three days instead of two, which time he first recommended. The reason for this was that a series of sixty preliminary tests gave the results shown in Table VI, which indicated that forty-eight hours is too short a time to allow the development of all the gas-forming organisms present.

TABLE VI — POSITIVE REACTIONS WITH BILE MEDIUM AT VARIOUS PERIODS

Period of incubation.	Average positive results.	Average per cent. gas.
48 hours	77 per cent.	10
72 hours	92 per cent.	24
96 hours	95 per cent.	38

For the first three months of regular use, October to December, 1906, the bile test gave good results, yielding positive tests in crude sewage in one-millionth of a cubic centimeter. In January, however, either the number of colon bacilli greatly decreased or the bile obtained was antiseptic. In April *B. coli* could not be isolated by this method from one one-thousandth of a centimeter of sewage.

IV. COMPOSITION OF CRUDE SEWAGE

The sewage of the south Metropolitan district was made slightly weaker in October, 1904, by the diversion of the flow from its more outlying areas into the new Peddock's Island high level sewer. Comparing the analyses of 1904–05 with those of 1903–04, a diminution of about 10 per cent. in the strength of the sewage was apparent. The analyses made since 1905 are not comparable with preceding ones, since both nitrogen and oxygen-consumed methods were changed at the beginning of the present investigation.

TABLE VII — Composition of Crude Sewage

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	52	235	120	133	35	10.7	5.0	13.5	0.1	0.2	51	35	3.2
1906	1	43	245	110	125	46	8.9	6.4	13.1	0.0	0.4	58	46	5.6
1906	2	56	285	140	127	40	7.7	5.5	15.0	0.0	0.3	60	45	2.0
1906	3	72	314	160	149	60	9.8	6.9	15.0	0.1	0.0	59	44	0.2
1906	4	54	295	125	116	34	9.5	6.0	14.5	0.0	0.1	59	46	2.5
1907	1	42	320	115	149	46	9.5	6.0	12.5	0.1	0.2	57	45	6.5
1907	2	55	260	80	146	46	7.5	4.5	14.0	0.0	0.0	51	39	3.8
Average	. . .	53	279	121	135	44	9.1	5.8	13.9	0.0	0.2	56	43	3.4

The average analysis of the crude sewage for each quarterly period from October, 1905, to June, 1907, is shown in Table VII. Most of the constituents were fairly constant throughout the whole period. The first quarter of the year is characterized by a marked increase of dissolved oxygen and a diminution of free ammonia, due to the inhibition of bacterial decompositions by low temperature. The second quarter of the year is marked by a decrease in organic nitrogen, due to the greater dilution of house sewage at that season with street washings and melted snow. At the same time, the free ammonia value rises with the rising temperature and more active bacterial decomposition. On the whole, the analyses indicate that the sewage used in these experiments was of about average strength for an American sewage. It is weaker than the sewages of many small Massachusetts cities where the proportion of house sewage is large. On the other hand, its organic content is slightly greater than that of the sewage of Columbus (Johnson, 1905). The "oxygen-consumed" value is 56 for Boston against 51 for Columbus; the free ammonia value 13.9 against 11; and the Kjeldahl nitrogen figure 9.1 against 9. Columbus sewage contains only 79 parts of volatile suspended solids, while Boston sewage has 91, but shows 130 parts of fixed suspended solids against 44 parts for Boston.

The average bacterial content of the crude sewage from October, 1906, to April, 1907, inclusive, was 1,200,000 per cubic centimeter as

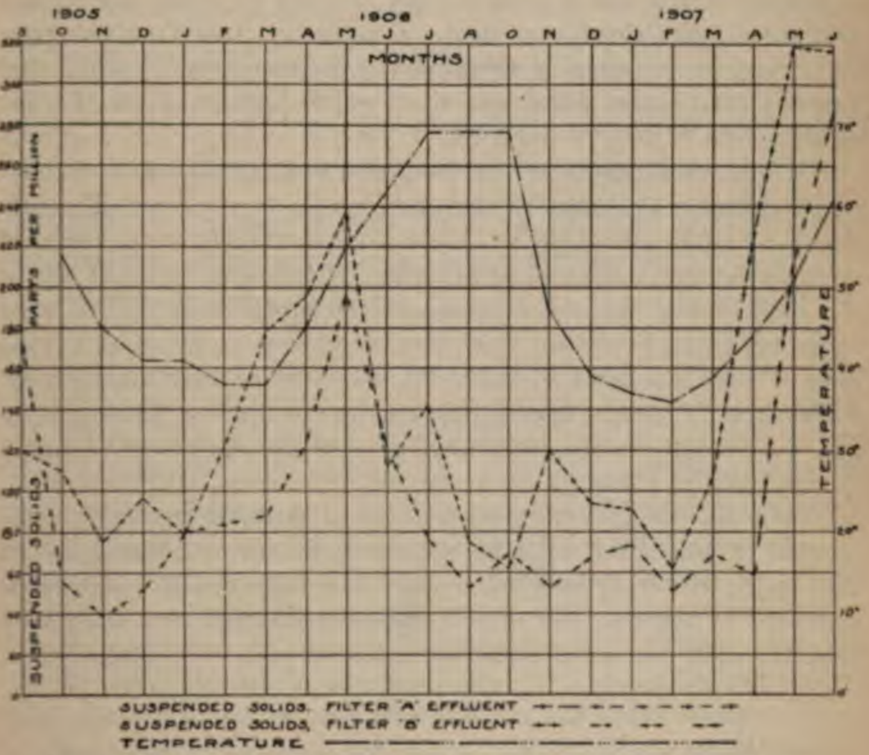


FIG. 12.—MONTHLY VARIATIONS IN TEMPERATURE AND SUSPENDED SOLIDS IN TRICKLING EFFLUENTS

determined by plating on litmus-lactose-gelatin at 20°. Of these, 20 per cent. were acid formers and 8 per cent. liquefiers. The average number of bacteria during the summer months would no doubt have been considerably higher, as shown by previous investigations (Winslow, 1905).

V. RESULTS OF SEPTIC TREATMENT

The septic system used in this investigation consisted, as already stated, of five tanks, each 6 feet long, 4 feet broad, and 3 feet deep.

These were connected by 2.5-inch pipes, and each contained a large baffle projecting from one corner nearly to the opposite corner, as shown in Figure 1. The path of a particle of liquid in each tank was about 10 feet long, and the action of all five tanks approximated that of a single tank 50 feet long and 3 feet wide.

Experiments were begun August 29, 1905, with all five tanks in series, but Nos. 2 and 3 were cut out October 19, 1905, and for one year three tanks alone were used. October 15, 1906, the two extra tanks were again placed in connection with the others. For the first year the total septic period was about seven hours, and for the last eight months it was twelve hours.

On the second day after the tanks were first started a scum formed, which gradually thickened so that after seven days it was sufficiently strong to retain gas bubbles. Masses of black sludge were observed rising to the top of the tank and floating. Conditions remained almost the same during the entire course of the investigation. The scum varied somewhat in amount from time to time, never attaining a thickness of over a quarter of an inch, and often entirely disappearing. Tanks Nos. 1, 4, and 5 operated for twenty months, and Tanks Nos. 2 and 3 for eight months, without any superficial indication of undue accumulation of solids.

There are two distinct processes involved in septic treatment — the removal of suspended solids by sedimentation and the liquefaction of the organic matter by bacterial action. The first of these processes is measured by the character of the effluent discharged, and Table VIII indicates what our septic tanks accomplished from this standpoint.

TABLE VIII — COMPOSITION OF SEPTIC EFFLUENT

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
					Total.	Fixed.	Total.	Solution.				Total.	Solution.
1905	4	52	175	70	86	16	7.9	5.0	14.3	. .	. .	45	36
1906	1	43	190	80	60	7	7.2	5.9	16.0	. .	. .	57	45
1906	2	58	215	93	105	21	6.3	3.7	18.6	0.1	0.1	61	43
1906	3	73	203	98	72	24	6.9	5.1	19.2	0.0	0.0	64	45
1906	4	53	220	85	52	15	7.5	5.5	17.0	0.0	0.0	56	46
1907	1	44	240	80	77	15	6.0	4.0	16.0	0.0	0.0	58	49
1907	2	55	250	105	118	31	3.5	1.0	21.5	0.0	0.0	59	42
Average	. .	54	213	87	81	18	6.5	4.3	17.5	0.0	0.0	57	44

Comparing the analyses of the septic effluent with those of the crude sewage (Table VII), it appears that the tank system removed 40 per cent. of the total suspended solids and 59 per cent. of the fixed suspended solids. There was a 28 per cent. decrease in the total organic nitrogen and, curiously enough, a 26 per cent. decrease in the organic nitrogen in solution. This latter point shows that the septic tank exercises a certain bacterial purification besides its primary sedimentary action. On the other hand, and, indeed, as a result of the decomposition of organic nitrogen, the tank effluent showed a 26 per cent. increase in free ammonia. "Oxygen-consumed" values were about the same in the effluent as in the crude sewage.

Some interesting points are brought out by a study of the quarterly analyses, which are plotted, for the more important constituents in Figures 5 to 11. Taking the organic matter first, it appears from Figure 7 that the removal of this type of material as a whole does not vary materially from season to season. Figure 8 shows, however, that the soluble organic nitrogen is much more strikingly reduced during the second and third quarters of the year than at other times. At the same season, as appears from Figure 9, the production of free ammonia in the septic tank increases rapidly. These phenomena are both, of course, correlated with the increased bacterial action which follows the setting in of warm weather. The same close relation between septic action and temperature has been shown by Kinnicutt and Eddy (1902), in their study of the gases formed in a closed septic tank. This point is of much importance in plans for the use of septic tanks under varying climatic conditions, as Fowler has pointed out. In India septic tanks work to perfection, while in Russia they are unsatisfactory (Fowler, 1907).

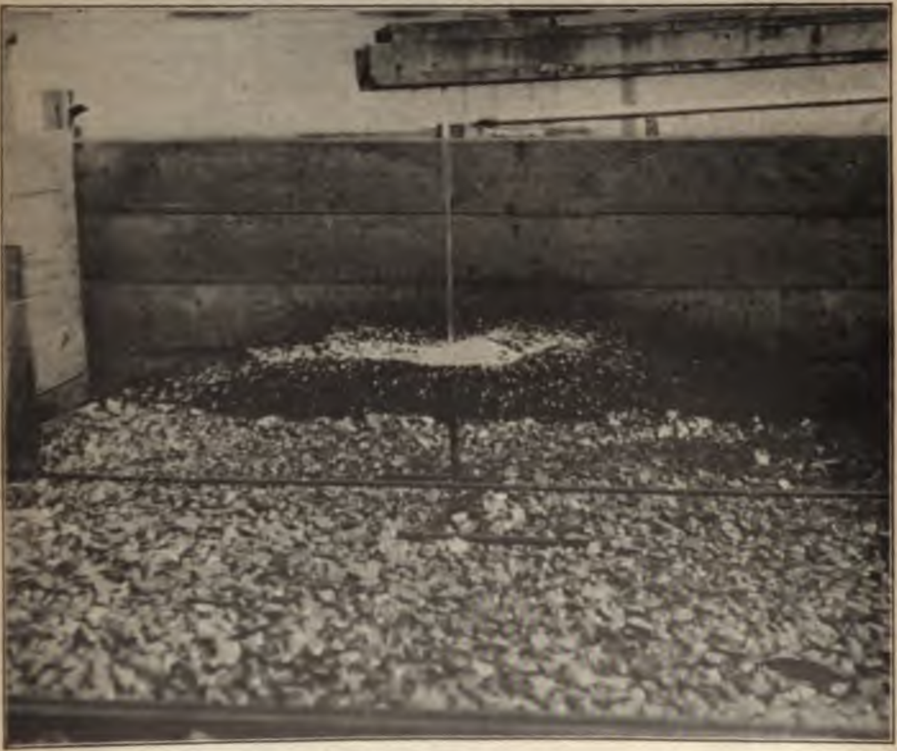


FIG. 13.—VIEW OF GRAVITY DISTRIBUTOR IN OPERATION

Turning to Figures 5 and 6, it appears that the septic tank is least efficient in the removal of suspended solids just at the time when its period of greatest biological activity begins; that is, in the second quarter of the year. This we explain by the active fermentation which manifests itself in the lifting of masses of sludge from the bottom of the tank and the general stirring up of its contents, and naturally leads to the discharge in the effluent of a larger proportion of suspended matter than at times of comparative rest.

Figures 10 and 11, showing the relations for carbonaceous matter, as indicated by the "oxygen-consumed" test, are somewhat surprising from the close parallelism which they indicate between the sewage and the septic effluent. Matter of this class was apparently not appreciably decomposed and scarcely affected by sedimentation. The alternative to this conclusion is to suppose an actual removal of carbonaceous matter, balanced by the production of new reducing bodies. It is difficult to suppose that such a process would yield the uniform results indicated by Figure 11. English septic tanks show, as a rule, a distinct loss of "oxygen consumed" (Winslow and Phelps, 1906*a*).

We believe that differences in results of this sort at different places are to be explained in part, at least, by the different methods in use in determining the oxygen-consumed value. The more vigorous the oxidizing action of the permanganate the more nearly the results approach the true total carbon values. Changes in the nature of the carbonaceous matter, which do not affect its total amount, are quite obscured by analytical procedures like the present standard method, involving a long period (half an hour) of boiling. The less intense English cold methods, on the other hand, give results which are markedly dependent on the nature as well as the amount of the carbonaceous matter. They are therefore extremely valuable in studying those slight chemical changes which accompany sewage purification. It is even possible to detect a difference between the results of the present standard method, involving a half-hour boiling, and the older Massachusetts method of two minutes' boiling, used in this laboratory two years ago. By the latter method our six septic tanks showed an average removal during two years of 14 per cent. of the total "oxygen consumed," as compared with no removal whatever in the present series as determined by the present standard method.

One notable point brought out by these diagrams is the fact that the change from three septic tanks to five, made in October, 1906, did not appreciably alter the character of the effluent. Judged by the analytical results, seven hours' storage is apparently sufficient to effect all the septic changes which will take place in this particular sewage.

The extent to which it accumulates sludge is quite as important a point in the working of a septic tank as the character of its effluent. This point was studied by the method used in our previous investigations. On three occasions — June 30, 1906, when the tanks had run eight months; July 1, 1907, after they had run twenty months;

and August 3, 1907, after they had stood without the addition of fresh sewage for one month — the inlets and outlets of all the tanks were closed and the contents of each tank, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table IX. The analyses refer to the total liquid and solid contents of each tank at the time its operation ceased, a suspension containing about 98 per cent. of water. The sludge was estimated by allowing the mixed tank contents to settle in a cylindrical vessel for twenty-four hours and observing the relation between the thick sediment produced and the clear supernatant liquid. The thickness of the sludge (which as measured by this method includes the scum) was about 4 inches after the first year of operation, and averaged nearly a foot at the end of the investigation.

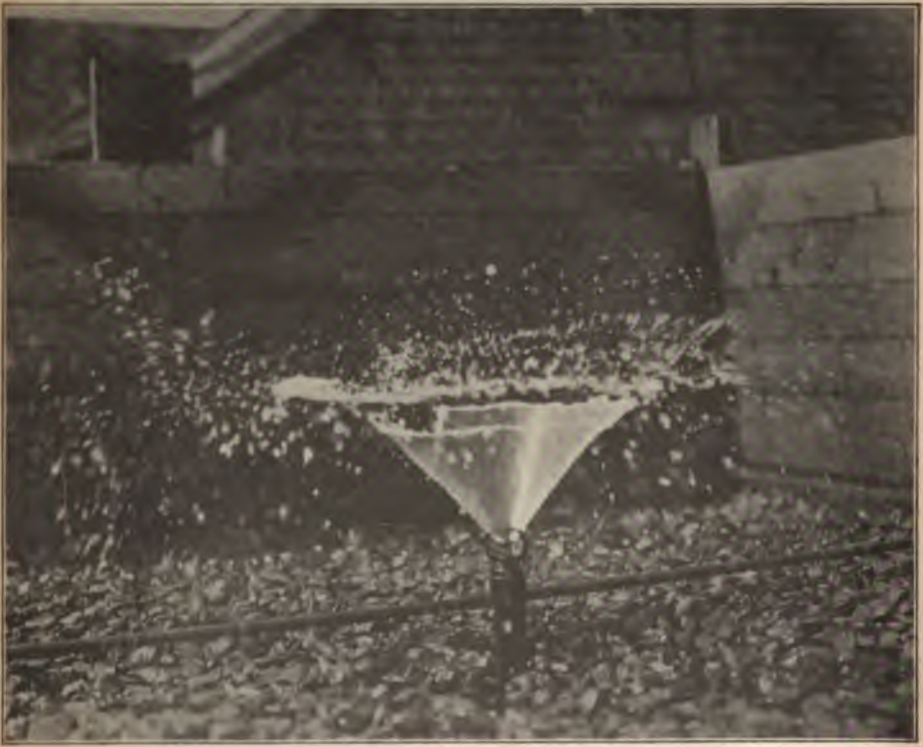


FIG. 14.— VIEW OF COLUMBUS SPRINKLER IN OPERATION

TABLE IX — ANALYSES OF SEPTIC TANK CONTENTS, INCLUDING SLUDGE AND SCUM

(Parts per Million)

Date.	Tank.	Liquid contentr.	Depth of sludge.	Solids.		Organic nitrogen.	Oxygen consumed.
				Total.	Volatile.		
		Gallons.	Feet.				
June, 1906	1	518	0.3	7,600	3,900	..	770
	4	498	0.2	4,400	2,200	..	520
	5	444	0.3	9,900	4,500	..	1,200
July, 1907	1	450	0.9	..	..	1,000	9,000
	2	468	1.1	..	..	1,400	9,800
	3	468	0.8	..	..	860	7,300
	4	486	0.9	..	..	1,100	9,400
	5	495	0.5	..	..	610	5,200
August, 1907	1	450	0.7	25,000	4,000	380	4,900
	2	468	0.5	18,000	3,200	290	3,700
	3	468	1.1	46,000	9,700	500	7,400
	4	486	1.1	38,000	3,000	560	7,000
	5	495	1.2	44,000	7,700	540	7,000

It appears from Table IX that the differences between the individual tanks at a given time were only such as would be expected from sampling errors with a thick organic suspension. The composition of the liquid in the three (or five) tanks was approximately the same at a given time, and the system may therefore be considered as a whole.

Comparing the 1906 analyses with those made at the end of the twenty-one months, it is evident that the amount of fixed solids in the tanks increased considerably during the course of the experiments. The same thing is true of oxygen consumed, and in each case the increase is more than proportional to the time of operation. This is, perhaps, partly due to the fact that during the first year the system was operated with a seven-hour period, and during the second year with a twelve-hour period. Our previous investigations have shown that long storage periods are associated with the undue accumulation of sludge (Winslow and Phelps, 1906 *a*), and similar observations have been made at Lawrence (Massachusetts, 1901).

Over-septic sewage may inhibit the action of the liquefying organisms, or there may occur a secondary precipitation of inorganic reducing bodies, iron compounds, for example. Too much aging seems, at any rate, to be associated with an increase in fixed solids and in oxygen consumed. The same phenomenon occurs when sludge is stored in a bottle in the laboratory. Table X shows the results of successive analyses of two samples of septic sludge so tested in July, 1906. The mere aging of the septic system as a whole might tend to increase such reactions during the second year. At London and at Leeds a gradual deterioration of septic effluents was noted with the increasing âge of the tanks (Winslow and Phelps, 1906*a*).

TABLE X — SEPTIC SLUDGE BEFORE AND AFTER STORAGE

(Parts per Million)

Storage, days.	Fixed solids.	Volatile solids.	Oxygen consumed.
0	33,600	35,880	7,040
2	43,500	36,400	9,960
5	52,560	35,840	10,960
0	30,900	31,400	7,360
2	34,200	26,3[illegible]0	8,340

The effect of a month's rest of the septic tanks is shown by a comparison of the analyses for July and August, 1907. The total amount of sludge did not change materially, but the oxygen-consumed value was slightly reduced and the organic nitrogen dropped more than 50 per cent. Suspended solids were still, however, very high. It is evident that after nearly two years of operation our septic system was approaching the limit of its capacity. With a foot of sludge in the bottom of the tanks, equal to 35 per cent. of the tank capacity, the effluent might soon have been expected to deteriorate. It is probable, therefore, that septic tanks operating with Boston sewage would require emptying once in two or three years.

A somewhat clearer idea of the actual work of the septic tanks may be gained by reducing the analytical data to the actual quantities they represent. During the twenty-one months of the investigation 2,490,000 gallons of sewage passed through the septic system. This volume of sewage carried 2,790 pounds of suspended solids (of which 1,880 pounds were volatile) and 188 pounds of organic nitrogen. The effluent leaving the tanks bore 1,670 pounds of suspended solids (of which 1,300 pounds were volatile) and 134 pounds of organic nitrogen. The septic system, therefore, removed 1,120 pounds of solid matter (580 pounds volatile and 540 pounds fixed) and fifty-four pounds of organic nitrogen.

TABLE XI—STORAGE AND DECOMPOSITION OF ORGANIC MATTER IN SEPTIC TANKS

Percentages of Sewage Value

	SUSPENDED SOLIDS.		Organic nitrogen.
	Fixed.	Volatile.	
Sewage	100	100	100
Septic effluent	41	69	71
Removed by tank	59	31	29
Stored in tank	62	6	4
Decomposed in tanks	3*	25	25

* Precipitated.

There were left stored in the tanks, after twenty-one months of operation and one month's rest, 675 pounds of solids (of which 109 pounds were volatile) and eight pounds of organic nitrogen. Four hundred and seventy-one pounds of volatile solids and forty-six pounds of organic nitrogen had, therefore, been decomposed in the tanks, while the fixed solids had been increased by twenty-six pounds—additional evidence of the precipitation of inorganic solids previously alluded to. These results are shown in the form of percentages in Table XI, where their relations may be somewhat more easily grasped.

On the whole, it appears that the septic tank will remove nearly two-thirds of the fixed suspended solids from Boston sewage and about one-third of the organic matter, as measured by suspended volatile solids or organic nitrogen. Of the organic matter in the sludge thus removed four-fifths is decomposed. The fixed solids, on the other hand, accumulate to such an extent as to require the cleaning of the tanks once in two or three years. A seven-hour period gives as good an effluent as a twelve-hour one, and probably produces a less accumulation of sludge. All these results harmonize very closely with those obtained in the previous experiments of 1903–05 (Winslow and Phelps, 1906 *a*).

The average bacterial content of the septic effluent for the eight months, October, 1906, to April, 1907, was 750,000, a reduction of

38 per cent. as compared with the crude sewage. The proportion of acid formers and liquefiers was about the same as in the sewage, 16 per cent. of the former and 8 per cent. of the latter. The results of the bile test for *B. coli* were somewhat erratic. In October and November the number of gas formers was apparently increased by passage through the septic tanks; in October 19 per cent. of the tests in one-millionth of a cubic centimeter were positive in the sewage and 56 per cent. were positive in the septic effluent; in November 9 per cent. of the tests were positive in the sewage and 38 per cent. in the septic effluent. From December to April negative results were consistently obtained in one-millionth of a cubic centimeter. The crude sewage showed 19 per cent. of positive results in December, 11 per cent. in January, 12 per cent. in February, and none in March and April.

VI. Results of Trickling Filtration

The general construction of the two trickling filters has been already described and is shown in Figures 1, 2, and 3. Both were 8 feet deep, and the surface of each was a square, approximately 10 feet on a side. Both were filled with 1½ to 2 inch broken stone. Filter A received crude sewage and filter B septic effluent.

The exact area of filter A was 98.47 square feet, or .00226 acre; of filter B, 94.57 square feet, or .00217 acre. The rate on each bed during operation was 200 gallons per hour for twenty-two hours each day, a gross rate of approximately 2,000,000 gallons per acre per day. During the summer months the plant was shut down on Sundays, while in winter it was run continuously to obviate the chilling of the bacteria in the empty bed. In September, 1906, the whole plant was shut down for two weeks. Careful records of operating time show that the filters were operated for 12,450 hours in the ninety-one weeks from October 1, 1905, to July 1, 1907. This means an average operation of 137 hours a week, or 5.7 days. The total amount of sewage applied to each bed was 2,490,000 gallons — an average of 3,900 gallons a day. The net rate of operation was, therefore, 1,730,000 gallons per acre per day for filter A, and 1,800,000 gallons per acre per day for filter B.

Each filter was at first equipped (August 21, 1905) with four gravity distributors — copper disks, 3 inches in diameter, with a 6-inch radius of curvature. Those on the septic side corroded badly, and on November 1 four new disks were substituted on each side to test the durability of various alloys. Pure aluminum proved as bad as copper, but three alloys — brass, bronze, and a nickel bronze — gave no indications of corrosion. No trouble was experienced in any case on the crude sewage filter.

The winter of 1905–06 was a fairly mild one, as may be seen by reference to Table XII, in which the maximum and minimum temperatures for the three winter months are tabulated from the published data of the United States Weather Bureau. The "normal" December temperature at Boston for different days of the month varies between 27° and 35° F., the normal January temperature between 24° and 31° F., the normal February temperature between 23° and 31° F. Ice first formed on the filters November 11, 1905, and by January 10 all the sprinklers were covered with mantles of ice — tubes about 1 foot in inside diameter, continuous from the box above the sprinkler to the surface of the bed. Inside this mantle all the sewage was distributed, and the areas between the four 1-foot circles were covered with 6 to 8 inches of ice.

In August, 1906, a slight pooling of sewage was observed on the beds, particularly on filter A. On digging into the beds it appeared that just under the four sprinklers the stones were clogged with black sludge. This layer was turned over with a pick to about a foot in depth on filter A, but no material was removed. It was evident, however, that the four sprinkling disks, each operating at a rate of .8 gallon per minute, were not distributing satisfactorily; and this experience illustrates the importance of proper distribution in trickling filters. In the middle of November changes were made in the distributing system as previously described. Filter A was equipped with a single gravity disk just like the four previously used, and filter B was equipped with a pressure nozzle of the Columbus type, and dosed intermittently from a siphon tank. The new distributors in normal operation are shown in Figures 13 and 14.

After this change no difficulty was experienced in securing a satisfactory working of the filters at all times. There was no tendency to surface pooling; analytical results were good, and, as will be seen later, there was no important accumulation of material in the beds. The winter of 1906–07 was much more severe than the previous one, and more severe than the average. Minimum temperatures fell below 5° F. on fifteen different days. On twelve days the maximum temperature was under 20° F.; for five successive days in January and

TABLE XII — MAXIMUM AND MINIMUM DAILY TEMPERATURES FOR WINTER MONTHS

(Degrees Fahrenheit)

United States Weather Bureau

December, 1905.		January, 1906.		February, 1906.		December, 1906.		January, 1907.		February, 1907.	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
33	12	41	22	47	24	47	20	50	30	36	21
54	26	23	26	28	6	20	12	20	12	42	30
61	30	35	22	18	—1	24	11	40	30	41	17
39	28	38	26	42	16	16	4	57	38	20	14
35	22	43	37	43	15	26	13	42	35	21	10
38	25	41	31	20	3	54	29	45	34	20	8
46	35	34	27	23	9	48	4	58	40	24	6
35	36	25	16	20	9	14	1	41	37	30	16
39	36	28	10	26	28	18	13	43	17	26	14
37	18	26	9	27	23	40	18	36	12	39	22
32	15	35	16	25	12	32	14	45	35	37	7
28	30	54	34	28	24	25	9	38	21	17	2
44	30	37	33	40	24	26	25	34	22	27	1
38	13	37	25	40	26	24	29	34	26	52	26
23	8	35	24	36	13	53	33	29	16	37	28
32	20	52	33	33	10	49	35	16	1	42	26
37	19	42	32	34	18	37	33	9	—4	39	20
51	25	44	31	37	27	36	12	35	9	26	16
44	33	38	25	45	32	30	10	42	29	37	14
47	36	46	24	53	32	44	24	58	34	36	28
51	38	68	46	63	42	45	36	34	18	38	14
50	40	63	48	48	34	41	33	34	17	19	4
41	37	68	53	38	28	34	15	17	—2	13	—2
38	28	60	26	48	31	24	12	8	—7	23	0
37	24	26	19	42	31	27	20	16	4	34	11
41	28	34	20	48	32	31	20	22	13	22	4
51	32	48	29	35	19	43	25	19	10	24	6
55	36	46	35	20	9	40	34	28	13	26	2
58	38	36	16	. .	. .	47	36	29	12	. .	. .
45	37	48	25	. .	. .	41	38	32	11	. .	. .
44	35	56	37	. .	. .	53	38	27	6	. .	. .

for four successive days in February the maximum temperature was under 25° F. (see Table XII). Yet ice and snow collected only at the outer edge and corners of the filters, leaving the main part of their surface clear. The condition of the beds at their worst is shown in Figures 15 and 16. The Columbus nozzle kept open a slightly larger circle, but built up a higher wall of ice at the periphery, owing to its intermittent action. It is interesting to note in Figure 16 the extra ice formation at the two points where the knife-edge supports of the spraying nozzle slightly diminish the flow of sewage. Both methods of distribution, however, worked excellently under the severe winter conditions, and the effluents remained well up to standard.

The analyses of the effluents from filters A and B are tabulated by quarters in Tables XIII and XIV. Regular analyses were not begun till October, 1905, but special analyses during the first month of operation showed that the beds rapidly attained a normal activity. Three parts per million of nitrates were found after a week's operation in the effluent of filter A and five parts in the effluent of filter B. The effluents were extremely turbid at first, and after a month still showed more oxygen consumed than the sewage. By the middle of October, after six weeks of operation, turbidity and organic matter decreased, and the beds assumed their normal operation.

TABLE XIII—COMPOSITION OF EFFLUENT FROM FILTER A

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	47	155	85	104	27	7.6	2.9	11.6	1.0	3.8	41	24	7.6
1906	1	29	170	110	130	51	6.0	3.9	12.1	0.5	4.0	40	27	9.3
1906	2	53	300	205	186	88	7.6	3.4	13.2	1.8	4.3	51	29	4.7
1906	3	69	183	108	104	45	8.1	3.6	9.3	2.5	3.9	39	24	4.9
1906	4	52	185	155	88	40	6.1	2.9	9.5	0.6	4.5	36	25	7.7
1907	1	29	210	115	87	28	4.9	2.3	8.9	0.3	5.4	33	22	11.2
1907	2	51	270	170	209	130	8.2	2.7	8.5	0.7	5.2	46	26	10.2
Average	. .	50	200	136	138	58	7.1	3.1	10.4	1.1	4.4	41	25	7.9

TABLE XIV — COMPOSITION OF EFFLUENT FROM FILTER B

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	45	90	45	72	20	5.6	2.7	12.0	0.9	4.1	31	24	8.0
1906	1	39	130	60	83	38	4.9	3.5	14.3	0.1	4.3	31	22	9.3
1906	2	62	215	140	155	85	4.9	2.3	15.3	1.2	4.4	40	23	4.4
1906	3	60	128	66	62	28	6.4	3.4	11.3	3.3	4.5	35	26	5.4
1906	4	52	120	65	50	22	6.0	2.0	11.5	1.2	4.6	33	26	7.6
1907	1	37	145	65	61	22	3.7	1.8	10.7	0.7	5.0	33	27	10.2
1907	2	52	200	105	198	46	3.2	1.1	13.3	1.0	5.7	38	26	8.2
Average	. .	51	147	78	96	37	5.8	2.4	12.6	1.2	4.7	34	25	7.6

From the Tables VII, VIII, XIII, and XIV and from Figures 5 and 6 it appears that the total amount of suspended solids discharged by each filter was slightly in excess of that received by it. An average value of 135 parts per million in the crude sewage was increased to 138 in filter A, and a value of 81 parts in the septic effluent was increased to 96 parts in filter B. A very interesting seasonal curve is indicated, however. The amount of solid material was less in the effluent than in the applied sewage except in the second quarter of the year. In some quarters, filter A effected a 40 per cent. reduction in suspended solids. In the second quarter of each year, there was an enormous increase of suspended solids in the effluent to a point in excess of the amount in the applied sewage. This means, of course, that the suspended solids of the sewage are ordinarily held on the bacterial films which cover the stones, while during the second quarter the accumulated material is washed out again into the effluent. We suspected at first that spring rains might account for this phenomenon, but a more careful study showed that the increase of solids in the effluent did not correspond to heavy rainfall, and it appeared from calculation that this factor could not be of great importance. Two inches of rain falling in an hour would double the rate on a 2,000,000-gallon per acre filter, but such a storm rarely occurs in the latitude of Boston. Monthly values for suspended solids and temperature, which have been tabulated in Table XV, show, on the other hand, a suggestive correlation.

TABLE XV — SUSPENDED SOLIDS AND TEMPERATURE OF TRICKLING EFFLUENTS

Month.	Filter A.		Filter B.	
	Temperature F.	Solids.	Temperature F.	Solids.
September, 1905	. .	120	. .	173
October	55	110	54	56
November	46	75	45	39
December	41	97	41	52
January, 1906	40	79	41	80
February	39	122	38	. .
March	37	178	38	88
April	46	195	45	124
May	55	237	55	197
June	61	112	62	121
July	69	142	69	76
August	70	75	69	52
September	. .	. .	. .	. .
October	69	62	69	70
November	48	120	47	58
December	40	94	39	68
January, 1907	39	91	37	74
February	37	62	36	51
March	40	107	39	69
April	44	223	44	59
May	51	319	51	213
June	60	316	61	288

The figures in Table XV are tabulated in graphic form in Figure 12. Both filter effluents show a progressive decrease of solid material from May onward till the early spring, when a sudden increase occurs. The trickling filter evidently has its own definite yearly life cycle, and upon this, rather than upon the applied solids, do the solids in the effluent depend. It seems probable that the bacterial films upon the stones absorb or otherwise hold the solid material which reaches them until by this process of accretion and their own multiplication the mass becomes heavy enough to break away. With Boston sewage a year's supply of solids can thus be stored; but the bacterial multiplication set up, when warm weather begins, serves to upset the equilibrium of the bed, and the solids collected during the preceding ten months are discharged. It will be noted, however, by reference to Figure 12, that solids began to increase in A effluent before the onset of warm weather. In each year its rise preceded that of B by two months. This bed received a considerably larger amount of suspended solids than filter B, and it seems probable that the mere accumulation of material began to cause the detachment of zoögloea before the spring increase in growth occurred. There is at any rate abundant evidence here that the trickling bed automatically frees itself from suspended solids after accumulation has taken place to a certain extent. This phenomenon will militate strongly against permanent clogging of the trickling bed.

In this connection the nature of the suspended matter is also of significance. In filter A the volatile suspended solids were reduced, on the average, from 91 parts to 80 parts, while fixed suspended solids were increased from 44 parts to 58; in filter B volatile suspended solids fell from 63 parts to 59, while fixed suspended solids rose from 18 parts to 37. The larger increase of fixed suspended solids in the septic side is probably due in part to the precipitation of iron sulphide, a deposit of which was later found on the bottom of the bed. In filter A, however, there is no evidence of such a reaction, and the figures seem to indicate a real conversion of organic matter into some insoluble mineral form. It is apparent to the eye that the suspended matter in the effluent of a trickling filter is quite different from that which goes on at the top. It is in much larger particles, as may be seen by the eye, and it settles much more easily. It is for this reason that the turbidity of both effluents was considerably reduced (200 for filter A against 279 in the sewage, and 147 for filter B against 213 in the septic effluent). Microscopic examination by the Sedgwick-Rafter method (Whipple, 1905), carried out under our direction by Mr. H. S. Spaulding, showed that the finely divided particles of suspended matter, of a size less than five standard units, were reduced from 300,000 per cubic centimeter in crude sewage to 28,000 in trickling effluent, while the larger particles, and particularly the macroscopic particles, were increased in numbers. In appearance the material in the trickling effluent is structureless and somewhat flocculent, resembling the amorphous matter so frequently found in water analysis. In its formation the original suspended matter applied to the filter has evidently been thoroughly worked over. It is somewhat surprising, in view of these facts, that the sum of the suspended matter applied and discharged should tally so nearly.

In organic content both effluents show a marked reduction. The purification per cent., as measured for each of the principal constituents, is shown in Table XVI. The results are remarkably close, with the exception of the total "oxygen-consumed" value for the septic side, which exception may be accounted for by the precipitation of iron compounds already alluded to. In all other cases there was a reduction of about 25 per cent. in total organic matter and 40 per cent. in organic matter in solution.

TABLE XVI — PURIFICATION EFFECTED BY TRICKLING BEDS

Percentages

	ORGANIC NITROGEN.		Free ammonia.	OXYGEN CONSUMED.	
	Total.	In solution.		Total.	In solution.
Filter A	22	47	25	27	42
Filter B	23	44	28	40	43

Figures 7 to 11 show that in general the organic matter in the effluent does not exhibit any marked seasonal variations. There is one striking exception, however, to this rule. From Figure 11 it appears that the total "oxygen-consumed" value rose inordinately in the second quarter of each year. This is evidently correlated with the increased discharge of suspended solids at the same time, and it is clear, since no corresponding increase in nitrogen occurred, that the organic matter which then appeared in the effluent was chiefly carbonaceous. This fact strengthens the possibility that the material discharged from the trickling bed is largely bacterial zoöglœa.

Two other points only demand special mention, the dissolved oxygen in the effluents and their content of mineral nitrogen. Dissolved oxygen was at all times present in both effluents in considerable amounts. It was highest in the first quarter of each year, when bacterial decompositions were checked by the cold, and it was distinctly higher during the second year than the first, owing to the better system of distribution. The values for nitrites and nitrates are plotted in Figure 17. Nitrites were at a maximum in both effluents in the autumn of 1906; since the 1907 curve stops at July 1 it is uncertain whether the same phenomena would have been repeated in that year. It is apparent, however, that the process of nitrite formation is markedly favored by high temperatures. The curve for nitrates, on the other hand, shows a pretty steady increase from the beginning to the end of the experiments, and indicates a progressive improvement in nitrifying power. Taking the sum of the organic and ammoniacal nitrogen in applied liquid and effluent, in comparison with the sum of the nitrates and nitrites, it appears that filter A received 23 parts of unoxidized nitrogen (organic and ammoniacal) and discharged 17.5 parts of unoxidized and 5.5 parts of oxidized nitrogen, nitrates, and nitrites. Filter B received 24 parts of unoxidized nitrogen and discharged 17.6 parts of unoxidized and 5.9 parts of oxidized nitrogen. There is, therefore, no evidence of appreciable storage or loss of nitrogen in filter A, and filter B shows a difference of only half a part. Table XVI shows that the per cent. purification effected by filters A and B was approximately equal as regards organic matter. Since the liquid applied to filter B had undergone preliminary treatment in the septic tank its effluent was, of course, actually superior to that of filter A. It contained only 96 parts of suspended solids against 138 parts for filter A, 5 parts of organic nitrogen against 7.1 parts, and 34 parts of oxygen consumed against 41 parts. Its free ammonia content was, however, higher, making the sum of the ammonia and organic nitrogen practically the same in both cases (17 6 and 17.5). The only significant difference between the effluents lay, therefore, in the fact that filter A discharged more suspended solids, both fixed and volatile, than filter B.

These results of chemical analysis are of considerable theoretical interest as throwing light on the processes which go on in the trickling bed; but, as we have pointed out already, they do not adequately measure the practical value of the purification effected. Neither the analyses of the effluents nor the figures for purification per cent. would by themselves suggest that our beds were doing satisfactory work. The methylene blue test, on the other hand, showed that the effluents of both filters were for the most part stable, and it is this test which furnishes the true criterion of their quality.

The methylene blue test was made on each effluent daily from February, 1906, to the end of the experiments, and the results are plotted in Figures 18-*A* and 18-*B*. The black blocks indicate the periods of decolorization by days up to fourteen days, the maximum time of observation.

During the cold months of February and March, 1906, results were notably irregular for both effluents. The sample collected on one day might prove stable, while that of the next would decolorize in two or three days.

With the beginning of warm weather, which favors harmful putrefactive changes, both before and during the process of filtration, both effluents further deteriorated. Filter B recovered about the end of May, and throughout the summer its effluent was generally stable. Filter A remained in poor condition until September, and was uncertain in its action for two months longer. The contrast between these beds brings out very clearly the great delicacy of the methylene blue method of testing effluents. The analyses for the third quarter of 1906 in Tables XIII ,and XIV show, indeed, a slight superiority for

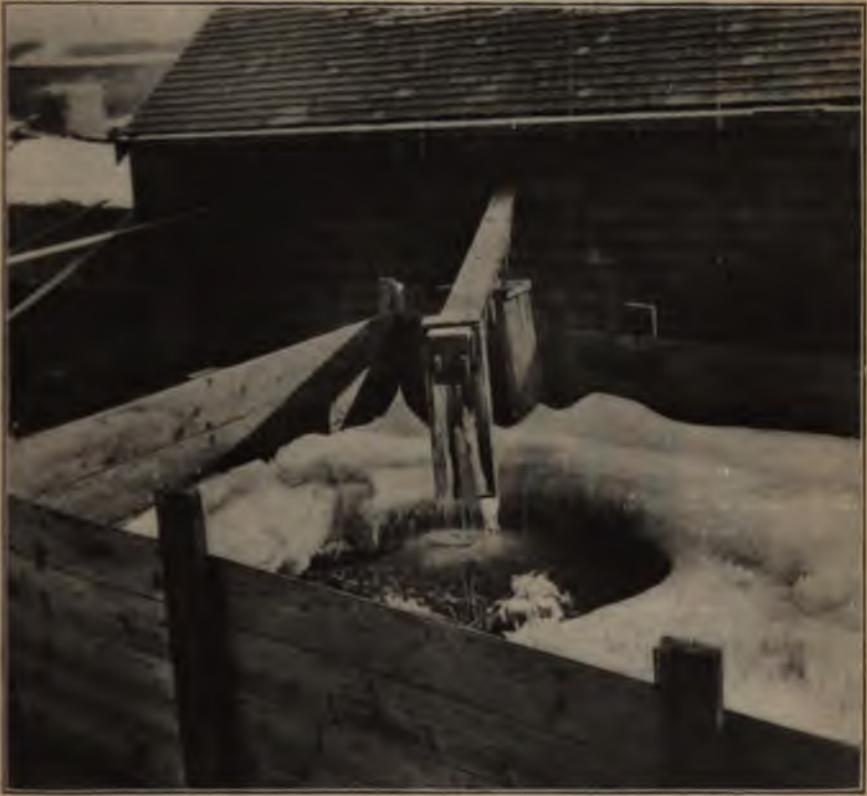


FIG. 15.—VIEW OF GRAVITY DISTRIBUTOR UNDER SEVERE WINTER CONDITIONS

filter B, but it is far too slight to lead to the conclusion that at this time one of the filters was practically a success and the other practically a failure.

With the installation of the new sprinklers in November, 1906, a decided change was manifest. After the middle of December, by which time the filter organism had become adjusted to its new conditions, both effluents were almost constantly stable. Occasionally, particularly during the winter months, and with filter A, a putrescible effluent was obtained, but this was rare. From December 15, 1906, to June 28, 1907, 156 samples of each effluent were examined by the methylene blue test. On the crude sewage side 127 samples were stable for fourteen days, nineteen more were stable for over four days, and ten only became decolorized in four days or less at 20°. The effluent of filter B showed 129 samples stable for fourteen days, sixteen more stable for more than four days, and eleven which were decolorized in four days or less. In other words, on 93 per cent. of the days both effluents were of sufficiently good quality to retain free oxygen for over four days.

Three conditions appear mainly responsible for imperfect operation when it did occur. In the first place, excessively low temperatures evidently impair the activity of the purifying organisms. The break in the curve for both filters on February 28, 1906 (see Fig. 18-*A*), was coincident with a fall from 19° to 9° F. The bad results obtained during the first week of December, 1906, accompanied minimum temperatures of 4° to 9° F. (Fig. 18-*B*). After the new distributing apparatus was in good working order, however, this effect of cold weather was only slight. Thus the severe weather of January 16 to 18, January 23 to 25, February 11 to 13, and February 22 to 24, 1907 (see Table XII), shows only slight effects in Figure 18-*B*.

The second factor affecting the stability of the effluents was the spring discharge of suspended solids. This phenomenon in April, 1906, evidently caused the bad break in the quality of the effluents manifest at that time and indicated in Figure 18-*A*. The interesting point in this connection is, however, that the much larger amount of suspended solids washed out in the second quarter of 1907 (see Fig. 5) produced no corresponding increase in putrescibility; that is, with proper distribution the solids discharged are so well oxidized or otherwise rendered stable that they do not interfere with the stability of the effluent.

The third factor which affects the character of the effluent unfavorably is irregularity in the operation of the filter. In Figure 18-*A* the sample taken after a day's rest (the Monday sample) appears again and again the worst of the week, and during the second year the only serious interference with the work of filter B followed the three days' rest of May 18 to 21. This action was always most marked in cold weather. Whether it is due to the injury of the bacteria in the filter by changed conditions or to the detachment of dried zoöglœa is uncertain. It is clear, however, that resting the filter is detrimental to the effluent, and the results for the second quarter of 1907 show that the necessary removal of accumulated material can be accomplished in a natural way without such unfortunate results. We are therefore led to conclude that extended periods of rest for the recuperation of the bed and drying up of the accumulated organic material are not only unnecessary, but actually detrimental, and that the operation of a trickling filter should be made as constant and uniform as possible.

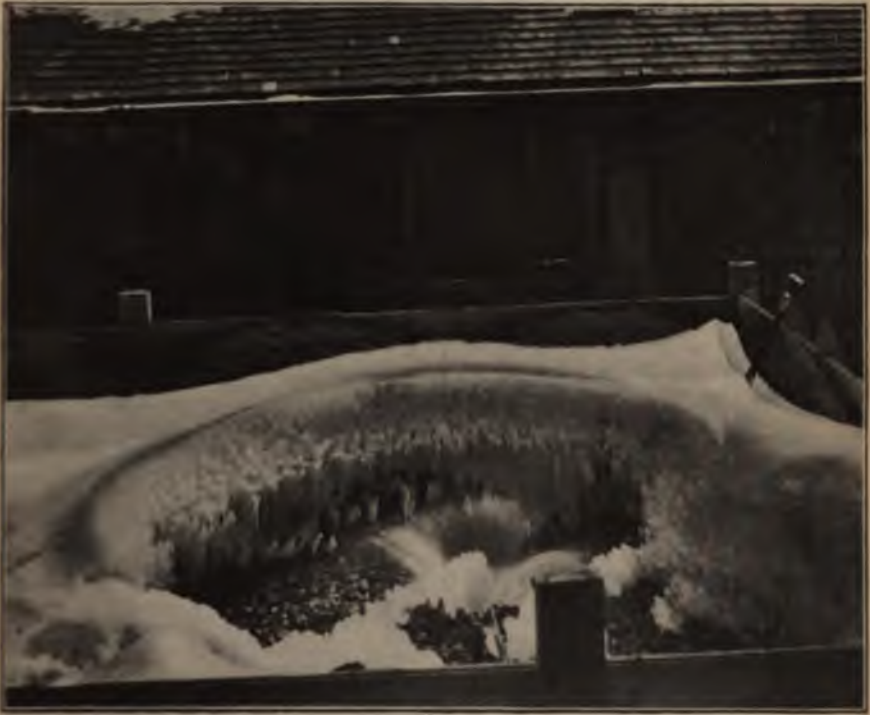


FIG. 16.—VIEW OF COLUMBUS SPRINKLER UNDER SEVERE WINTER CONDITIONS

TABLE XVII — STABILITY OF TRICKLING FILTER EFFLUENTS

Percentage of Samples Decolorized at Each Specified Period

"A" Effluent.										Total samples.
Days		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14+	
Year.	Quarter.									
1906	1	40.5	18.9	2.7	5.4	8.1	0.0	0.0	24.4	37
1906	2	42.6	26.0	20.6	2.7	2.7	2.7	0.0	2.7	73
1906	3	23.7	38.9	15.3	5.1	6.8	0.0	0.0	10.2	59
1906	4 *a*	2.4	9.5	14.3	4.8	9.5	7.1	2.4	50.0	42
1906	4 *b*	2.9	11.4	2.9	8.6	11.4	2.9	8.6	51.3	35
1907	1	2.7	4.1	6.7	2.7	2.7	4.1	8.1	68.9	74
1907	2	4.4	2.9	1.5	0.0	1.5	2.9	1.5	85.3	68

"B" Effluent.										Total samples.
Days		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14+	
Year.	Quarter.									
1906	1	38.8	16.7	5.5	8.4	8.4	5.5	2.8	13.9	36
1906	2	16.9	22.6	26.7	2.8	9.8	1.4	1.4	18.4	71
1906	3	11.9	15.3	10.2	5.1	0.0	0.0	3.4	54.1	59
1906	4 *a*	2.3	0.0	0.0	0.0	4.5	2.3	2.3	88.6	44
1906	4 *b*	14.6	20.4	14.6	11.6	2.8	5.8	5.8	24.4	34
1907	1	4.0	4.0	0.0	2.7	1.3	0.0	4.0	84.0	75
1907	2	5.8	0.0	5.8	5.8	1.4	0.0	0.0	81.2	69

The results of the methylene blue test for each quarter are indicated in Table XVII, samples being divided by their decolorization periods into eight classes, those which decolorized inside of two days, between two and four days, between four and six days, etc., the last class including those which were still stable after fourteen days. The fourth quarter of 1906 is divided so as to differentiate the samples collected before and after the change in the distribution system.

The table shows in each case poor results with the old system of distributors. Filter B treating septic effluent was much better than filter A, however, and showed a steady improvement during this period. When the Columbus sprinkler was installed on filter B a serious temporary derangement followed; but by January, 1907, the filter had become adjusted to the new conditions, and for the last six months yielded effluents, 93 per cent. of which were stable for four days and over 80 per cent. stable for fourteen days. The substitution of a single gravity distributor instead of four on filter A was followed by a steady improvement. Ninety-three per cent. of the samples of A effluent have been stable for four days since January, 1907, and the percentage stable for fourteen days rose from nearly 70 per cent. in the first quarter of the year to 85 per cent. in the second.

Bacterial examinations showed an average of 200,000 bacteria per cubic centimeter in the effluent of filter A and 180,000 in the effluent of filter B. The figures correspond to removals of 83 per cent. and 76 per cent., respectively, figured on the applied liquid. The proportion of acid formers and liquefiers was about the same as in the crude sewage.

At the close of the twenty-one months of experimentation the trickling filters were dug out and carefully examined. Samples of the filtering material were taken at various points; the accumulation between the stones was carefully removed by washing with a brush and the resulting liquor analyzed. In both filters the top of the beds was quite clean. In filter A there was an accumulation of fine material extending from 3 inches down for about a foot just under the four old distributors. This deposit covered four circles, each about a foot and a half in diameter, and was, of course, chargeable to the earlier imperfect process of distribution. In this layer, where the maximum deposit occurred, the extraneous matter amounted to .3 pound per cubic foot, of which 44 per cent. was organic. The remainder of filter A showed no visible accumulation of foreign material, and the underdrains and concrete floor of the bed were as clean as when they were laid. In filter B there was a slight deposit from 6 inches to 18 inches below the surface, amounting to .07 pound per cubic foot, while the remainder of the bed was clean. On the floor of B, however, there was a deposit of sludge half an inch thick, amounting to 4 cubic feet in all (1,720 cubic feet, or 64 cubic yards, per acre). This sludge contained 22 per cent. of water and 1.4 per cent. volatile solids. Qualitative tests showed it to consist of a mixture of finely divided silica with a considerable proportion of sulphide of iron.

From the stone analyses at various depths we have calculated in Table XVIII the total amounts of material stored in each filter and the corresponding values per million gallons. The excess of nitrogen on the septic side is suggestive.

TABLE XVIII — STORAGE OF MATERIAL IN TRICKLING FILTERS

	Pounds per Filter.			Pounds per Million Gallons.		
	Fixed solids.	Volatile solids.	Organic nitrogen.	Fixed solids.	Volatile solids.	Organic nitrogen.
Filter A. Crude sewage	36.4	5.5	0.6	14.6	2.2	0.2
Filter B. Septic sewage	5.3	6.6	2.7	2.1	2.6	1.1

In addition to these deposits in the beds the sludge on the bottom of filter B amounted to 697 pounds, or 280 pounds of dry solids, per million gallons. Such material could easily be removed by washing with a hose in a filter with a properly constructed underdrainage system.

VII. SEDIMENTATION OF TRICKLING EFFLUENTS

The effluents from the trickling filter, although stable, contain so much suspended matter as to be unsightly, and under many circumstances further treatment for the removal of suspended solids would be desirable. As shown at many of the English plants and at Columbus (Johnson, 1905), such a removal may be accomplished by simple sedimentation, since the suspended particles in the effluent are sufficiently large to settle out with ease. Since January, 1906, the effluents from filters A and B have been treated in this manner. The tanks used for sedimentation have been described above, and their general construction is indicated in Figures 1 and 2. One of the tanks, photographed before it was put into place, is shown in Figure 19.

The tanks were of conical form, with a central vertical funnel which received the inflowing liquid at the top and discharged it into the body of the tank near its bottom. The supernatant liquid was carried off from the top by two surface channels, and sludge was drawn off by a valve at the bottom. The capacity of each tank was a little under 350 gallons, equivalent to a sedimentation of an hour and three-quarters. Experiments made by Mr. R. R. Patch in a thesis study showed that liquid dyes colored the whole surface of the tank in seven and a half minutes. On the other hand, when a culture of *B. prodigiosus* was poured into the central tube, plates made every five minutes from the outflowing liquid first showed the germ after one hour and gave maximum numbers after an hour and a half.

The character of the effluent from the sedimentation tanks is indicated by the quarterly average analyses in Tables XIX and XX.

TABLE XIX — COMPOSITION OF FILTER A EFFLUENT AFTER SEDIMENTATION
Quarterly Averages
(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	115	45	116	56	4.2	3.9	13.0	0.6	3.9	31	26
1906	2	165	85	53	15	3.8	2.3	13.8	2.1	4.3	36	31
1906	3	100	45	55	20	5.8	4.2	6.3	2.5	4.0	29	25
1906	4	90	50	30	12	4.5	3.0	9.0	0.7	4.5	30	27
1907	1	160	85	50	11	3.0	2.0	9.5	0.5	5.5	29	26
1907	2	135	60	83	29	3.5	2.0	9.5	0.9	5.4	31	25
Average	. .	128	62	65	24	4.1	2.9	10.2	1.2	4.6	31	27

TABLE XX — COMPOSITION OF FILTER B EFFLUENT AFTER SEDIMENTATION
Quarterly Averages
(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	90	30	40	14	3.9	3.2	15.0	0.1	4.4	26	23
1906	2	135	70	63	27	2.8	2.3	14.9	1.2	4.5	30	23
1906	3	76	45	31	11	5.2	4.0	10.7	2.9	4.6	30	28
1906	4	80	35	23	7	4.9	3.5	11.5	1.2	4.4	29	26
1907	1	115	50	34	12	2.5	1.5	10.5	0.8	5.0	31	28
1907	2	140	75	110	37	2.5	1.5	13.0	1.3	6.1	29	27
Average	. .	106	51	50	18	3.6	2.7	12.6	1.3	4.8	29	26

A comparison of the general averages in Tables XIX and XX with the average for the unsettled effluents in Tables XIII and XIV indicates the efficiency of the sedimentation process, and this efficiency has been expressed in purification per cent. in Table XXI.

TABLE XXI — PERCENTAGE PURIFICATION EFFECTED BY SEDIMENTATION

	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Oxygen Consumed.	
	Total	Fixed	Suspended.	Soluble.		Suspended.	Soluble.
A effluent	58	59	70	6	2	25	8*
B effluent	44	51	56	13*	4	46	4*

* = increase.

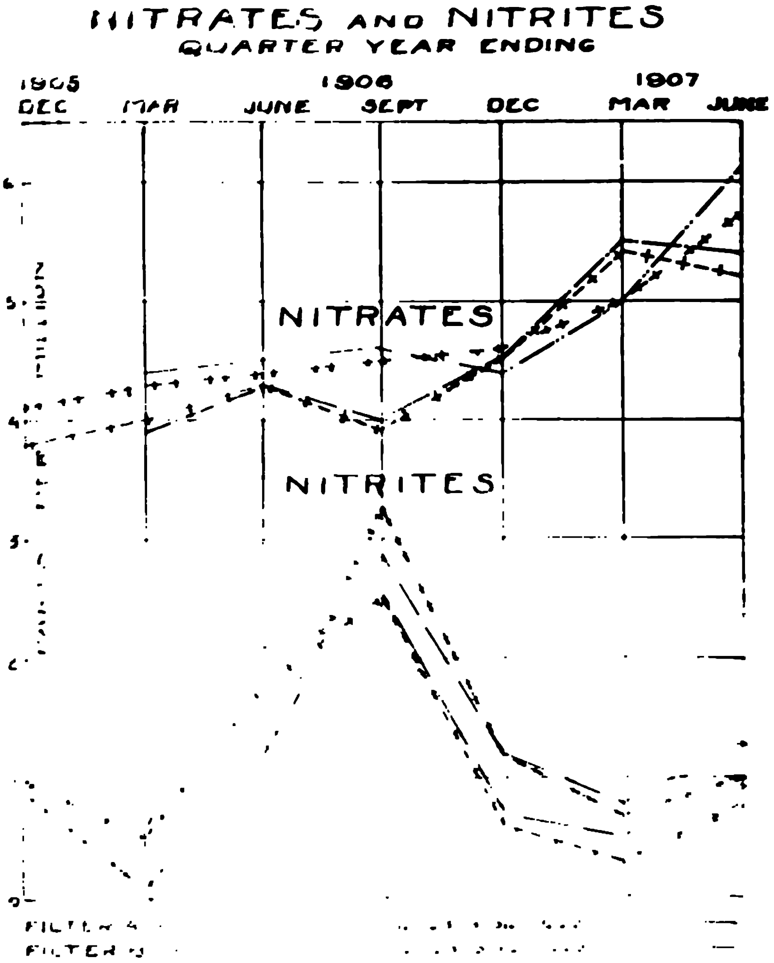
Sedimentation for two hours in the conical tanks used in these experiments removed about half the suspended solids present. The removal of suspended nitrogen and carbonaceous matter (oxygen consumed) was in each case greater than the removal of suspended matter in general. Coupled with the increase in soluble nitrogen and carbonaceous matter, this makes it clear that a certain amount of liquefying action went on at the bottom of the tanks. Nitrites and nitrates were unaffected, however, as may be seen by reference to Figure 17. It will be noticed that the per cent. purification effected was always less in the case of the septic effluent. This is, no doubt, because the liquid before treatment contained less gross material to remove. The finer portions of suspended matter naturally settle out less readily.

No important seasonal variations were noted in the action of the sedimentation tanks, except in the case of the organic nitrogen. This constituent, as plotted in Figure 7, was less reduced in the autumn months than at any other time, while at this period (the third quarter of 1906) the soluble organic nitrogen was largely increased. Its value rose from 3.6 to 4.2 in the case of A, and from 3.4 to 4 in the case of B effluent. This was, of course, due to the increased septic action going on in the tanks during the warm season. Bacterial results also indicated the existence of organic activity in the sedimentation tanks. The average number of bacteria in the settled effluent of filter B for the seven months — October, 1906, to April, 1907 was 260,000 an increase of 44 per cent. on the effluent entering the sedimentation tank.

The best measure of the efficiency of sedimentation is the methylene blue test, and the decolorization periods for the settled effluents are indicated by the unshaded blocks in Figures 18-*A* and 18-*B*. At times during the winter and spring of 1906 even the settled effluent was putrescible. In general, however, most of the effluents which putrefied in their original state were rendered stable when their solids were reduced by sedimentation. The months of July and August, 1906, furnish a good instance of this. During the whole period forty-nine samples were examined. Of the unsettled effluents forty-five from filter A and twenty from filter B became decolorized inside of fourteen days, but of the corresponding sedimented samples only ten from filter A and nine from filter B became decolorized. After the new distribution system was in working order twenty-nine samples from A and twenty-seven samples from B decolorized in less than fourteen days. Of the corresponding settled samples thirteen from filter A and seventeen from filter B became decolorized.

It must be remembered in interpreting these results that our tanks were not of the best form for securing efficient sedimentation. Their shape was conditioned by the head room at our disposal, and a deeper tank, more of the usual Dortmund shape, would give better results. Furthermore, the pipe for removing sludge from our tanks was so small that sludge could not be drawn off rapidly, and considerable stirring up of the contents of the tank was the result. With tanks of proper design, planned for a full two-hour flow and with proper arrangements for sludge removal, results would undoubtedly be better.

Against the advantages to be gained by the sedimentation of the trickling effluent must be set the new problem of sludge disposal which is introduced. Since September, 1906, this problem has been studied by careful measurement and analysis of the material removed from the sedimentation tanks, and the general results are brought together in Table XXII. The analyses are grouped by four periods, in which the method of removing sludge from the tanks differed as follows: From September to December 3, 1906, and from April 9 to June 29, 1907, twenty-five gallons of sludge and water were drawn from each tank every other day by the valve for removing sludge shown in Figure 2. The three samples for each week were chloroformed, mixed, and analyzed. Reference to Table XXII shows that by this method the liquid removed from the tank was considerable in amount and contained only 10 to 20 per cent. of true sludge. If sludge is removed as often as this it cannot be obtained in very compact form in tanks of such a construction as ours. From December 4, 1906, to January 14, 1907, sludge was removed once a week, the tanks being drawn down to a point 2 feet from the bottom. In this way a more concentrated liquid was obtained. During the third [illegible] January 24 to April 8, 1907 [illegible] samples were taken. [illegible] which produced no harmful re [illegible] and at the end of the period the tank was d



F[illegible] Nitrates and Nitrites

[illegible]

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS

riod (January 14 to April 8, 1907) no samples were tak idge was allowed to accumulate, which produced no harmful the cold weather; and at the end of the period the tank wa

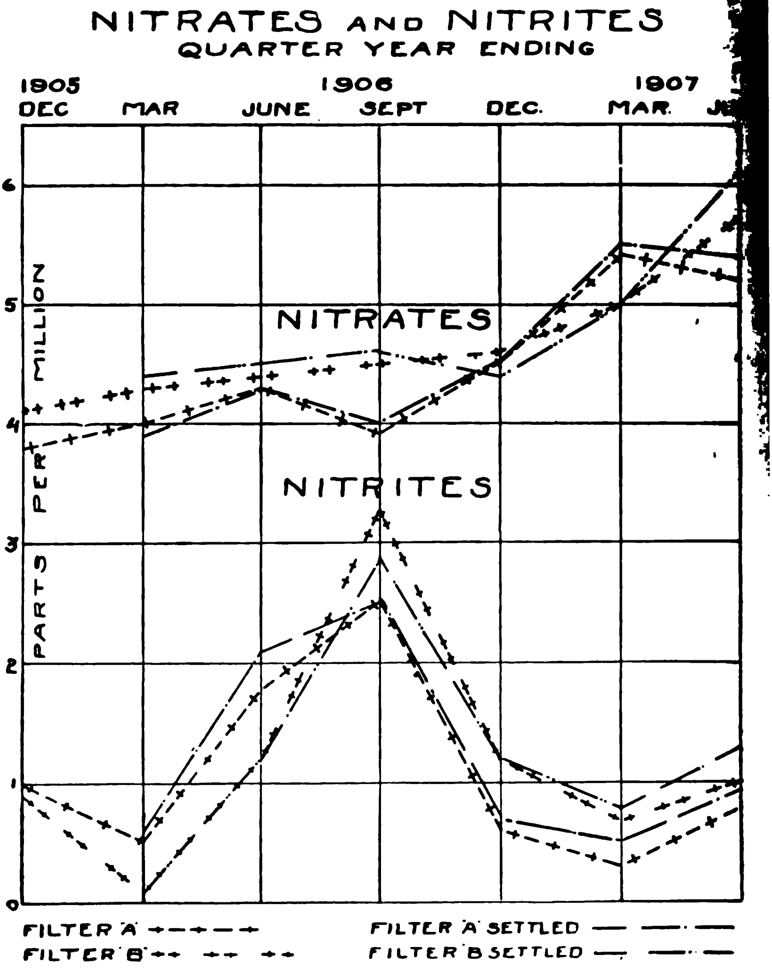


FIG. 17.—QUARTERLY VARIATIONS IN NITROGEN AS NITRATES AND NITRITES CRUDE AND SETTLED EFFLUENTS

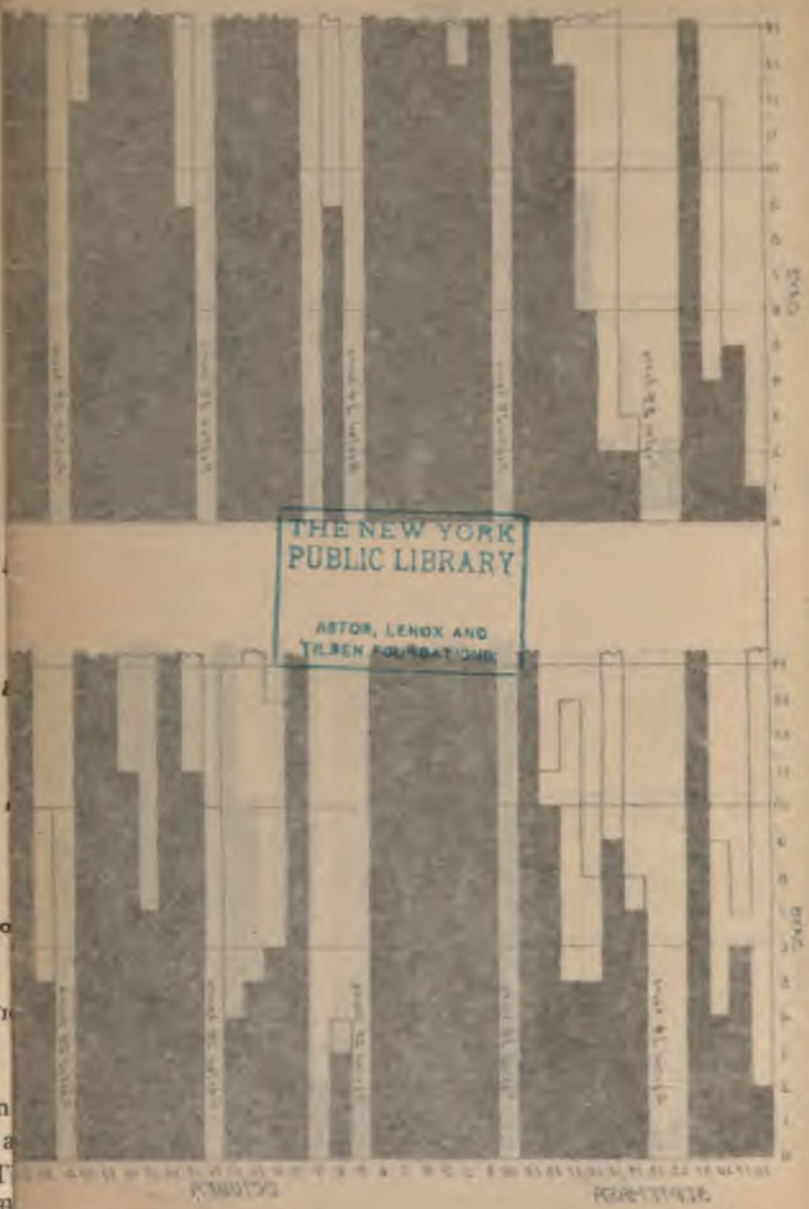
wn to a depth of 1 foot 9 inches, and the remaining liquid rem d analyzed.

The cubic yards of wet sludge removed in each period varied effluent from .40 to 1.29 and for B effluent from .18 to .73. Per

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS.

per
slu
in t



THE NEW YORK PUBLIC LIBRARY
ASTOR, LENOX AND TILDEN FOUNDATIONS

Fi

down
and a
T
A eff

TABLE XXII—AMOUNT AND COMPOSITION OF SLUDGE REMOVED FROM SEDIMENTATION TANKS

Period.	Total gallons sewage passed.	Gallons sludge and water removed.	Per cent. sludge.	Cubic yards wet sludge.	ANALYSIS OF SLUDGE, PER CENT.					POUNDS PER MILLION GALLONS SEWAGE.			
					Solids.		Organic nitrogen.	Carbon.	Specific gravity.	Solids.		Organic nitrogen.	Carbon.
					Loss.	Fixed.				Loss.	Fixed.		
A.													
September—December 3 . . .	276,000	825	15.5	0.636	4.07	5.07	0.195	0.45	1.049	155.0	193.0	7.40	17.10
December 4—January 14 . . .	151,800	90	90.5	0.405	4.32	5.84	0.190	0.45	1.049	184.5	257.0	8.35	19.80
January 15—April 8	285,200	490	38.0	0.925	3.72	3.81	0.150	0.35	1.034	200.0	206.0	8.06	18.90
April 9—June 29	246,000	900	29.0	1.290	4.22	5.12	0.215	0.30	1.028	361.0	439.0	18.40	25.80
B.													
September—December 3 . . .	276,000	825	10.2	0.420	3.81	3.85	0.223	0.45	1.045	96.5	97.5	5.70	11.40
December 4—January 14 . . .	151,800	90	42.0	0.185	3.99	4.43	0.195	0.38	1.042	82.6	92.1	4.05	7.89
January 15—April 8	285,200	490	30.0	0.730	3.30	3.56	0.220	0.20	1.036	138.0	151.0	9.40	8.50
April 9—June 29	246,000	900	16.0	0.712	4.53	3.39	0.205	0.33	1.025	220.0	165.0	9.96	16.10

lion gallons, the cubic yards of sludge removed were, for the four successive periods, 2.3, 2.7, 3.2, and 5.7 for filter A, and 1.5, 1.2, 2.6, and 2.9 for filter B. The increased values in the last two periods are due to the increased suspended solids in the effluents from the trickling beds during the spring rains. Taking the whole period from September to June, there were removed from the sedimentation tanks, per million gallons of sewage passed, on the crude sewage side, 3.40 cubic yards of sludge, with 237 pounds of volatile solids, 281 pounds of fixed solids, 11.2 of organic nitrogen, and 20.8 of organic carbon. On the septic side, per million gallons of sewage passed, there were 2.14 cubic yards of sludge, containing 136 pounds of volatile solids, 126 pounds of fixed solids, 7.5 pounds of organic nitrogen, and 11 pounds of organic carbon.

The volume of this sludge is evidently considerable. In composition it is naturally not so putrescible as its analysis would indicate, since it consists largely of the humus-like compounds formed in the trickling bed. Nevertheless, in concentrated form it is not generally stable, as shown by the fermentations already alluded to as going on in the sedimentation tanks. Mixed with the rest of the effluent these solids do not putrefy, as shown by the methylene blue tests of the unsettled effluent, and by the fact that nitrites and nitrates showed no diminution in the sedimentation tanks. By itself, however, the sludge will generally putrefy, and if it is removed by sedimentation some means must be found for its disposal. We attempted to purify it by straining through coke without success. Coarse coke allowed it to pass freely and fine coke clogged too rapidly to be of practical use. It will probably be found best under actual working conditions to discharge the tank contents on to sludge beds and dig the resulting deposit into the land. From the inconsiderable putrescibility of the sludge, this method of disposal could be accomplished with ease. It will, however, be a local question in each individual case whether the improvement effected in the trickling effluent by sedimentation compensates for the increased cost of settling and of sludge disposal.

VIII. Disinfection of Trickling Effluents

The trickling filter furnishes the best mechanism now available for accomplishing the primary object of sewage purification — the oxidation, or otherwise rendering stable, of organic matter. Often this is enough; but where shellfish industries or water supplies are menaced the bacteria too must be taken into account. For bacterial removal the rapid processes of sewage treatment are entirely inadequate. Comparing the effluent of filter B with the crude sewage, it is apparent that septic tank and trickling bed combined reduced the total number of bacteria from 1,200,000 to 180,000—a diminution of 85 per cent. Tests for *B. coli* during the summer of 1906 gave the results indicated in Table XXIII, the figures representing the average of thirty-five determinations.

TABLE XXIII—BACTERIA IN SEWAGE AND SEPTIC AND TRICKLING EFFLUENTS

	Bacteria per c.c. Lactose agar at 37°.	*B. coli.* Positive tests* in $\frac{1}{10000}$ c.c.
Sewage	1,300,000	65 per cent.
Trickling filter receiving sewage	750,000	35 per cent.
Septic effluent	1,650,000	66 per cent.
Trickling filter receiving septic effluent	750,000	35 per cent.

* By Jackson bile test.

Evidently during the warm weather there was a multiplication of bacteria in the septic tank, and the removal of total bacteria and of gas-forming organisms by the whole process was under 50 per cent.

These results are as good as can be expected from filters of coarse material, but they do not represent satisfactory bacterial purification. For this reason the Baltimore experts (Baltimore, 1906) suggested secondary filtration through sand for the effluents from their projected trickling filters, in order to avoid possible danger to the shellfish industry of Chesapeake Bay. The Board of Advisory Engineers estimated the cost of works for the complete treatment of 75,000,000 gallons of sewage per day at $3,283,250, of which sum $1,040,750, or over 31 per cent., was for the supplementary treatment on sand filters. The annual cost of operation was estimated at $115,500, of which $55,000, or 48 per cent., was for the supplementary treatment (Baltimore, 1906). This gives some idea of the price which it is necessary to pay for effluents of bacterial purity over and above the cost of rendering the sewage stable and non-putrefactive.

Fortunately a far cheaper and equally efficient method of removing bacteria is now at hand. The application of chemicals as a method of sewage purification—that is, as a method for the removal of organic material—has not proved successful except in rare instances, with sewage of peculiar composition. When organic stability has been attained, however, and bacterial removal only is desired, the problem becomes a wholly different one. Disinfection of sewage and effluents has been studied by various English observers, most exhaustively by Rideal (1905). The latter observer, in an extensive series of experiments at Guildford, studied the action upon raw and septic sewage, and upon the effluents from contact beds, of hypochlorites produced electrolytically from sea water by the oxychloride process. Great reductions in bacteria were obtained with 30 to 70 parts per million of available chlorine for the crude sewage, 25 to 44 parts for septic sewage, and .5 to 20 parts for contact effluents of varying grades of purity. The removal of *B. coli* was all that could be desired. Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group, aërobic, spore-forming bacteria. Absolute sterilization, however, required very high concentration of chlorine. Since American sewages are weaker than European, and trickling effluents more highly purified than those of ordinary contact systems, the outlook for disinfection seemed more favorable under our conditions, for the less organic matter present the less chlorine will be absorbed and prevented from exerting its disinfectant action. Phelps and Carpenter (1906), in a study of the problem on a laboratory scale, obtained the results indicated in Table XXIV.

TABLE XXIV—DISINFECTION OF TRICKLING EFFLUENT BY BLEACHING POWDER

(Phelps and Carpenter, 1906)

Experiment No.	Available chlorine. Parts per million.	ORGANISMS KILLED. PER CENT. OF INITIAL NUMBERS.				
		Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
I	3.5	98.7	. .	97.8	99.6	99.9
	10.6	98.9	. .	98.9	99.7	99.8
	55.0	99.9	. .	99.9	99.9	99.9
II	25.0	. .	99.8	99.9	. .	. .
	37.0	. .	99.94	. .	. .	. .
	100.0	. .	99.97	. .	. .	. .
III	2.0	. .	99.8	99.9	. .	. .
	5.0	. .	99.85	99.9	. .	. .
IV	0.25	. .	65.6	70.9	. .	. .
	0.50	. .	89.2	94.2	. .	. .
V	1.0	. .	81.5	99.1	. .	. .
	1.5	. .	99.6	99.9	. .	. .
VI	5.0	. .	98.2	98.2	. .	. .
	10.0	. .	. .	99.6	. .	. .

It was evident from these experiments that complete sterilization was a practical impossibility. Neither the addition of large amounts of bleaching powder, up to 100 parts of available chlorine per million, nor the storage of the effluent for periods of time up to twenty hours proved entirely effectual. On the other hand, a comparatively low concentration of chlorine applied for two hours gave a very large reduction, the residual organisms, as in Rideal's experiments, being almost entirely saprophytic spore formers. Sterilization is not feasible, but disinfection is.

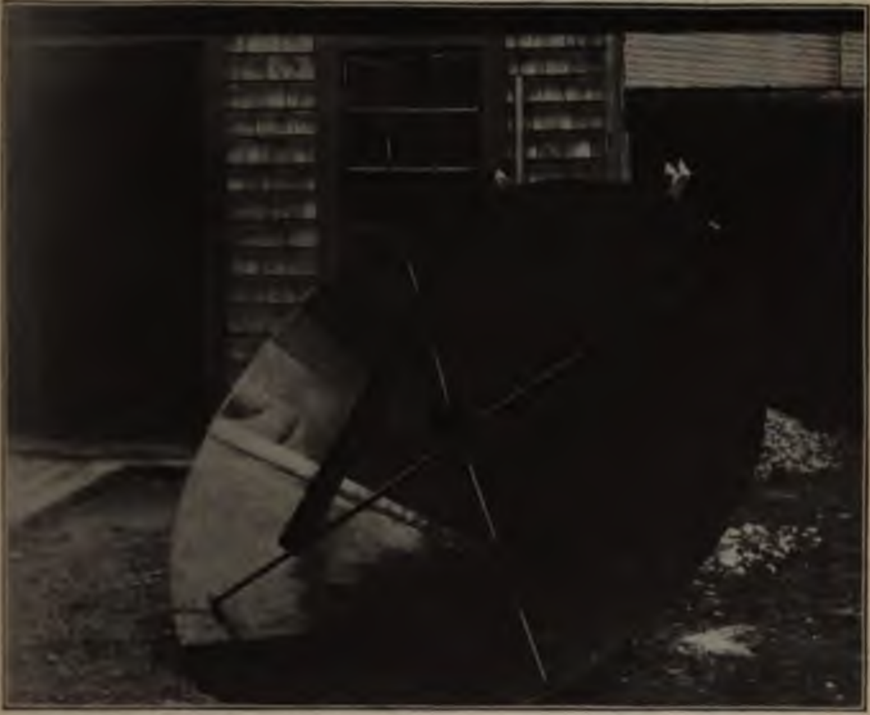


FIG. 19.—VIEW OF SEDIMENTATION TANK BEFORE IT WAS PUT IN PLACE

It is important to maintain the distinction between absolute sterilization and a reasonable percentage purification such as is obtained in water filtration. A neglect of this discrimination has led to the use of excessive quantities of lime in certain recent German experiments (Schumacher, 1905; Kranepuhl, 1907; Kurpjuweit, 1907). The character of the individual sewage, however, will of course materially affect the results obtained in a given case. A good efficiency has been reported in recent experiments on the disinfection of septic effluent at Bengal, India. On the other hand, Kellerman, Pratt, and Kimberly (1907) found considerable amounts of chloride of lime necessary for the treatment of septic and contact effluents in Ohio.

In August, 1906, we began to treat the effluent from filter A by adding chloride of lime solution from a small orifice box to the effluent as it flowed into the sedimentation tank. The solution was mixed once a day in a fifty-gallon barrel in such strength that when added to the effluent at the rate of two gallons per hour it would supply the effluent with about five parts per million of available chlorine. It was not possible on such a small scale to regulate the flow accurately, and there was some variation in the amount of available chlorine added to the effluent. This value was determined each day when the samples were taken for bacterial examination. It averaged about five parts per million, and the variation was no more than may be expected in the case of a larger plant with less careful supervision. Samples were examined before the disinfectant was added and at the outflow from the tank after a little less than two hours' contact.

TABLE XXV — EFFICIENCY OF DISINFECTION OF TRICKLING EFFLUENT WITH CHLORIDE OF LIME

(Available Chlorine, Five Parts per Million)

Date.	Organisms per Cubic Centimeter.		Gas Production in Bile Broth.	
	Before treatment	After treatment.	Before treatment. Dilution, [illegible] c.c.	After treatment. Dilution, 1 c.c.
August, 1906				
11	270,000	69	+ 0	+ 0
13	630,000	41	0 0	− 0
14	135,000	406	− −	+ 0
15	230,000	21	0 0	0 0
16	250,000	17	− 0	0 0
18	120,000	40	+ 0	− 0
20	90,000	74	− 0	0 0
21	220,000	22	+ +	+ 0
23			− +	+ 0
Average	240,000	[illegible]	[illegible]	22 per cent.
Average reduction		[illegible]		[illegible] per cent.

The results of bacterial examinations on nine different days during the period, as indicated in Table XXV, show a 99.96 per cent. removal of total organisms. With Jackson's bile test positive results were obtained in 33 per cent. of the tests made upon the untreated effluent at a dilution of one millionth, indicating that the organism was present on the average to the extent of about 330,000 per cubic centimeter. After treatment, positive tests were obtained in 22 per cent. of 1 c.c. samples, indicating that on the average there was an organism present in 5 c.c. of effluent. Upon this basis the average removal of fermenting organisms (presumably *B. coli*) was 99.993 per cent.

These results were so favorable as to indicate the entire feasibility of disinfecting the effluent from trickling beds by means of chlorine. Five parts of chlorine, the amount necessary to secure practical disinfection, could be applied at a cost of $1.50 per million gallons of sewage. We desired, however, to compare the efficiency of other disinfecting agents. Johnson and Copeland (1905) obtained good results with copper sulphate, but used amounts of copper and periods of storage which would make the cost of the process prohibitive. When our filters were put in operation after their rest in September, 1906, experiments were begun with copper sulphate. One part of copperas sulphate per million was added to A effluent from October 13 to November 19, and from November 20 to December 2 two parts were used in the same way. During the first period the average of examinations on fourteen days showed 230,000 bacteria per cubic centimeter before treatment and 34,000 afterward — a reduction of 35 per cent. During the second period (with two parts of copper per million) the average of examinations on seven days showed 240,000 bacteria per cubic centimeter before treatment and 18,000 after — a reduction of 92.5 per cent. Evidently copper is inferior to chlorine for the treatment of this effluent, since the cost of one part of copper is about equal to that of five parts of chlorine.

During January and February, 1907, no disinfectant was added to the effluent from filter A. Simple sedimentation showed for the average of fifteen determinations a reduction from 140,000 bacteria to 42,000 — a diminution of 70 per cent. At higher temperatures, when multiplication takes place in the tank, no such reduction would, of course, be observed. As noted above, the tank receiving B effluent showed a considerable net increase of bacteria in the period from October to April.

March 1 experiments were begun with a third disinfectant, sodium benzoate, which has been suggested for use in this connection. In March and April, 0.8 part per million gallons was added, and in May the quantity was doubled. For the first period the average of tests on twenty-six different days showed 140,000 bacteria per cubic centimeter before treatment and 54,000 afterward — a reduction of 62 per cent. For the second period the average of five determinations showed 370,000 bacteria per cubic centimeter before treatment and 84,000 afterward — a reduction of 78 per cent. Evidently sodium benzoate is not an economical disinfectant, since the application of one part per million gallons would cost $1 per million gallons.

There is one important factor to be taken into account in interpreting these results, that of temperature. The action of disinfecting agents follows the velocity laws of other chemical reactions, and rises with an increase of temperature. The chlorine work was, therefore, carried out under somewhat more favorable conditions than the experiments with copper sulphate and sodium benzoate. The difference between chloride of lime and the other agents tested was so great, however, as to leave little question of the practical superiority of chlorine for the treatment of our effluent. Recent work carried out by one of us for the New Jersey State Sewerage Commission at Red Bank, New Jersey, has shown that chlorine disinfection is entirely feasible at a low cost and on a practical scale.

IX. CONCLUSIONS AS TO THE BEST METHODS OF TREATING BOSTON SEWAGE, WITH AN ESTIMATE OF ITS APPROXIMATE COST

1. *Trickling Beds.* — The main result of this investigation has been to show the feasibility of treating Boston sewage on trickling beds so as to secure organic stability. In the experiments conducted, the filters were operated at a rate of about two million gallons per acre per day, which would call for fifty acres of stone beds for the treatment of the sewage now discharged at Moon Island. A comparison with the 133 acres of contact beds or 1,000 acres of sand beds, which would be necessary for other processes, indicates clearly that for this city the trickling bed offers the most practical method of treatment.

We have found that with good distribution a trickling bed 8 feet deep will operate successfully at all seasons, under local weather conditions. It removes about half the soluble organic matter, yielding an effluent which is somewhat turbid, but stable and well oxygenated. The organic matter present has been so worked over and purified by the bacteria in the filter as to be non-putrescible. Judged by the methylene blue reduction test 93 per cent. of the samples of the effluent are of such stability as to undergo no putrefactive change when kept closed up from the air for four days. Under ordinary conditions of discharge into open water such an effluent would be entirely unobjectionable.

The proper distribution on trickling beds can be attained either by the use of fixed sprinkler heads of the Columbus type, so arranged as to discharge intermittently at frequent intervals, or by the use of the splashing gravity distributors designed at the Experiment Station for this purpose.

With good distribution the trickling beds show no appreciable tendency to clog. During the greater part of the year solid matter accumulates on the surface of the stones throughout the bed, but when this storage reaches a certain point, usually in the early spring, the solids break away and come off in the effluent in a stable condition. In a period covering two years the total amount of solid matter coming off balanced that going on. The filtering material at the end of the experiments was in excellent condition and showed no storage of nitrogen.

Our results point strongly to the advantage of operating trickling beds under conditions as uniform as possible. Resting periods proved distinctly detrimental to the work of the beds, and constant operation is to be recommended rather than any process which involves alternate working and resting periods.

2. *Septic Tanks.*—It appears from our experiments that Boston sewage may be treated in the septic tank with excellent results, and that a period of seven hours is a sufficiently long one. Thus operated an open tank will remove 40 per cent. of the total suspended solids and 60 per cent. of the fixed suspended solids; its effluent shows a decrease of about 25 per cent. in organic nitrogen in solution and a corresponding increase in free ammonia. The septic action on the stored solids is an active one, four-fifths of the organic solids deposited disappearing in solution or as gas. Fixed solids gradually accumulate so as to render it probable that tanks would require cleaning about once in two years.

On the whole, our experiments indicate that the septic tank need not be used at all in the treatment of Boston sewage. Since November, 1906, when the distribution system was put in order, crude sewage has been treated on one of our trickling beds with perfect success. The effluent from this filter was less frequently putrescible than that from the bed which received septic effluent. The filter taking septic effluent showed a deposit on its floor, due to secondary reducing changes, which was absent from the crude sewage bed. Furthermore, the absence of the odors produced by spraying septic sewage is an advantage of considerable moment in favor of the process of treating fresh sewage. Combined with the saving of the cost of tanks (in the neighborhood of $250,000), these arguments seem to indicate the treatment of crude sewage directly on trickling filters as most desirable. Modern devices for ensuring a thorough preliminary screening should, however, be installed.

3. *Sedimentation of Trickling Effluents.* — The suspended solids which appear in the trickling effluent, though inoffensive, are unsightly, and in many locations might require removal. By a sedimentation of two hours we have found it possible to remove about half the suspended solids. This clarification was accompanied by an improvement in stability.

In the case of Boston the currents of the harbor would be amply competent to care for the solid matter discharged if that matter were of an inoffensive and non-putrescible nature. Experience with the system at present in use has indicated this quite clearly. For a comparatively slight improvement in stability it does not appear to us justifiable to go to the expense of installing secondary sedimentation tanks. The sludge accumulating in such tanks would amount to two or three cubic yards per million gallons of effluent — a serious problem in itself. We are therefore of the opinion that the effluent from the trickling beds may best be discharged directly into the harbor as it comes from the beds. A stable effluent under such conditions could cause no nuisance, and if a submerged discharge were provided its presence would scarcely be detected.

4. *Disinfection of Trickling Effluent.* — The problem of bacterial purification still remains to be considered, since the trickling bed produces organic stability without destroying pathogenic bacteria. In the case of Boston Harbor, with its large contiguous population, its bathers, and its shellfish industry, this aspect is an important one. The experiments carried out during the last two years have made it clear that

the effluents from trickling beds may be so purified bacterially by disinfection with chloride of lime as to be of much better quality than the present streams entering Boston Harbor. This bacterial purification requires about five parts of available chlorine per million gallons, and the cost of treatment would be within moderate limits.

The process of disinfection with chlorine can be applied to crude sewage as well as to trickling effluent, although experiments carried out at the station indicate that about double the amount of chlorine is needed, on account of the reducing action of the organic matter in the sewage. Pending the construction of a trickling filter plant for the treatment of the organic matter in Boston sewage, it might well be purified bacterially by this process at the present Moon Island outfall.

5. *General Plan for the Treatment of the Sewage of the South Metropolitan District.*—The sewage outfall of the south Metropolitan district at Moon Island is the one which threatens most seriously to menace the purity of Boston Harbor, and it is this sewage which will certainly first require some different method of treatment. We have, therefore, considered in a general way the practical problem of dealing with it in the light of the results of our experiments.

The most convenient location for a trickling filter area would be at the calf pasture in Dorchester, near the present pumping station. This is objectionable, however, on account of its proximity to the thickly settled portion of Dorchester. Furthermore, the necessity for excavating about 10 feet of mud and refilling in its place would greatly increase the cost of construction at this point. The same objections apply to certain waste areas on the Neponset marshes which suggested themselves as possibly available. The headland of Squantum would offer an ideal opportunity for building trickling beds, but the difficulties of obtaining land in another town militate against the use of this site.

The southern portion of Thompson's Island would furnish a location free from all the objections to which the other sites are open. On an embankment 1,500 feet long the sewage could be carried from Squantum across to the island, the effluent flowing back along the same embankment to the existing outfall sewer. The pumping station at Dorchester and the tanks and outlet at Moon Island could thus be used without substantial changes. We have made preliminary estimates of the cost of building fifty acres of trickling beds, 8 feet deep, and equipped with the gravity distribution system, and are of the opinion that the cost, including the embankment with its two sewers, an efficient grit chamber, a reasonable purchase price for the necessary land, grading, stone filling brought to the island by water, concrete construction, and sprinklers, would be in the neighborhood of $1,800,000.

If this capital sum were borrowed at 5 per cent. on a twenty-five year loan the annual expense for interest and sinking fund would be $126,800, paying off the entire cost in the twenty-five year period. As a matter of fact, we see no reason to suppose that at the end of this time the plant would not be good for another twenty-five years without substantial reconstruction. The cost of operation, including extra pumping and supervision of screens and filters, would amount to $70,000 a year, bringing the total cost to about $200,000 a year, or $5.50 per million gallons of sewage treated.[1]

The effluent from the trickling beds, wherever situated, could be further bacterially purified by disinfection with chloride of lime, at a cost of approximately $1.50 per million gallons, or $55,000 annually.

Pending the construction of filters for the removal of putrescible organic matter from Boston sewage, if it should seem desirable to secure bacterial purification, this may be effected by direct treatment of the crude sewage with chloride of lime, which could probably be done for $3 per million gallons, or $110,000 annually.

Experiments are now in progress at the Experiment Station to test the practicability of higher rates of filtration and shallower beds than those used in the experiments on which these calculations are based, as well as on the treatment of sewage and effluents by electrolytically produced chlorine. It is hoped that these experiments may lead to a material reduction in the estimated cost of the purification processes. It seems clear, however, that the combination of trickling filters and chemical disinfection will solve the Boston sewage problem satisfactorily; and in the light of present knowledge these two methods are the most efficient and economical available for the purpose.

REFERENCES

Baltimore, 1906. Report of the Board of Advisory Engineers and of the Chief Engineer on the Subject of Sewage Disposal. Made to the Sewerage Commission of the City of Baltimore.

Clark, H. W., 1907. Eight Years' Work with Trickling Sewage Filters at the Lawrence Experiment Station. Eng. News, LVII, p. 397.

---

[1] The authors desire to express their thanks to Mr. W. S. Johnson for assistance and advice in the preparation of these preliminary estimates.

Committee of the American Public Health Association, 1905. Report of Committee on Standard Methods of Water Analysis. J. Infect. Dis., Supplement No. 1.

Farnsteiner, K., 1902. Leitfaden für die chemische Untersuchung von Abwässer. Berlin, 1902.

Fowler, G. J., 1907. Sewage Experiments at Matunga, Bombay. Eng. News, LVIII. p. 146.

Goodnough, X. H., 1906. Examination of Sewer Outlets and of Tidal Waters and Flats from Which Shellfish Are Taken for Food. Thirty-Seventh Annual Report of the State Board of Health of Massachusetts for 1905, p. 411.

Gregory, J. H., 1906. Discussion on the Advance in Sewage Disposal. Trans. Am. Soc. Civil Eng., LVII, p. 128.

Jackson, D. D., 1906. A New Solution for the Presumptive Test for *Bacillus Coli.* Biological Studies by the Pupils of William Thompson Sedgwick, p. 292. Boston, 1906.

Johnson, G. A., 1905. Report on Sewage Purification at Columbus, Ohio. Columbus, 1905.

Johnson, G. A., and Copeland, W. R., 1905. Copper Sulphate as a Germicide. J. Infect. Dis., Supplement No. 1, p. 327.

Johnson, G. A., Copeland, W. R., and Kimberly, A. E., 1906. Relative Applicability of Current Methods for the Determination of Putrescibility in Sewage Effluents. J. Infect. Dis., Supplement No. 2, p. 80.

Kellerman, K. F., Pratt, R. W., and Kimberly, A. E. The Disinfection of Sewage Effluents for the Protection of Public Water Supplies. U. S. Dept. of Ag., Bureau of Plant Industry, Bull. 115, 1907.

Kimberly, A. E., and Hommon, H. B., 1906. The Practical Advantages of the Gooch Crucible in the Determination of the Total and Volatile Suspended Matter in Sewage. J. Infect. Dis., Supplement No. 2, p. 123.

Kinnicutt, L. P., and Eddy, H. P., 1902. The Action of the Septic Tank on Acid Sewage. Fourth Annual Report Connecticut Sewerage Commission, Hartford, p. 24.

Kranepuhl, 1907. Beiträge zur Frage der Abwasserdesinfektion mittels Chlorkalkes. Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, IX, p. 149.

Kurpjuweit, O., 1907. Zur Frage der Desinfektion ungereinigter und gereinigter städtischer Abwässer mit Chlorkalk. Mitteilungen aus der Königlichen Prüfungsanstalt für Wasser u. Abwässerbeseitigung zu Berlin, IX, p. 162.

Massachusetts, 1901. Thirty-Second Annual Report of the State Board of Health of Massachusetts for 1900. Boston, 1901.

Phelps, E. B., 1905. The Interpretation of a Sewage Analysis. TECHN. QUART., XVIII, p. 40.

Phelps, E. B., and Carpenter, W. T., 1906. The Sterilization of Sewage-Filter Effluents. TECHN. QUART., XIX, p. 382.

Phelps, E. B., and Winslow, C.-E. A., 1907. On the Use of Methylene Blue in Testing Sewage Effluents. J. Infect. Dis., Supplement No. 3, p. 1.

Rideal, S., 1905. On the Sterilization of Effluents. J. Roy. San. Inst., XXVI, p. 378.

Schumacher, 1905. Die Desinfektion von Krankenhausgruben mit besonderer Berücksichtigung des Chlorkalkes und ihre Kontrolle. Gesundheits-Ingenieur, XXVIII, p. 361.

Spitta, 1903. Weitere Untersuchungen über Flussverunreinigung. Arch. Hyg., XLVI, p. 64.

Spitta and Weldert, 1906. Indikatoren für die Beurteilung biologisch gereinigter Abwässer. Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, VI, p. 160.

Wellesley, 1907. Report of Committee on Sewerage Petition. Wellesley, 1907.

Whipple, G. C., 1905. The Microscopy of Drinking Water. New York, 1905.

Whipple, G. C., 1907. The Pollution of New York Harbor. Eng. News, LVII, p. 577.

Whipple, L., 1907. The Determination of the Organic Nitrogen in Sewage by the ldahl Process. TECHN. QUART., XX, p. 162.

Winslow, C.-E. A., 1905. The Number of Bacteria in Sewage and Sewage Effluents etermined by Plating upon Different Media and by a New Method of Direct Micro- al Enumeration. J. Infect. Dis., Supplement No. 1, p. 209; Contributions from the ary Research Laboratory and Sewage Experiment Station, I, p. 41.

Winslow, C.-E. A., and Phelps, E. B., 1905. The Chemical and Bacterial Composition f the Sewage Discharged into Boston Harbor from the South Metropolitan District. J. Infect. Dis., Supplement No. 1, p. 175; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, I, p. 7.

Winslow, C.-E. A., and Phelps, E. B., 1906 *a*. Investigations on the Purification of Boston Sewage. Water-Supply and Irrigation Paper No. 185, U. S. Geological Survey; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, II, p. 97.

Winslow, C.-E. A. and Phelps, E. B., 1906 *b*. The Trickling Filter at the Sewage Experiment Station of the Massachusetts Institute of Technology. Eng. News, LVI, p. 168.

Winslow, C.-E. A., Phelps, E. B., Story, C. F., and McRae, H. C., 1907. Studies of Sewage Distributors for Trickling Filters. TECHN. QUART., XX, p. 325.

[Reprinted from Technology Quarterly, Vol. XX, No. 1, March, 1907]

Contribution from the Sanitary Research Laboratory and Sewage Experiment Station

A METHOD FOR TESTING AND COMPARING SEWAGE SPRINKLERS[1]

By EARLE B. PHELPS

In the application of sewage to the surface of filters of the trickling or sprinkling type, evenness of distribution is an essential factor. This is more especially true in the case of filters whose material is of so coarse a nature that there is little or no lateral movement of the sewage within the bed. If on such a filter one-third of the surface is receiving two-thirds of the applied sewage, it is quite evident that the rate of filtration on that area is twice the mean rate. This rate would largely determine the character of the effluent, and an effluent of the same character could be obtained at twice the rate of filtration if the sewage could be distributed in a perfectly even manner over the whole area.

To accomplish this distribution over the surface of coarse-grained filters, many types of distributor have been devised. Among the more important of these may be mentioned: (1) Systems of fixed troughs, designed either to overflow or to discharge through notches or orifices; (2) delivery arms rotating over circular beds, operated either by the flow of the sewage or by power, distributing through nozzles or by overflowing; (3) large overflow troughs moved laterally back and forth over the bed; and (4) fixed sprinkler heads (pressure sprinklers) discharging upward under pressure, or discharging downward (gravity sprinklers) upon sprinkling or spattering disks. The distribution effected by these various methods is necessarily more or less uneven, and the efficiency of a given system may be defined as the evenness of the resulting distribution, a perfect distribution being one in which each small unit of area is receiving its proportionate share of the sewage. Such a condition is approached, in theory at least, by well-designed distributors of the second and third types enumerated. Their efficiencies depend upon proper leveling, unobstructed openings, and other details of design and operation which need not be gone into. Distributors of the first type mentioned cannot give perfect distribution. They distribute in lines, and as these lines are brought nearer and nearer together the distribution becomes more nearly perfect. In the Stoddart distributor the limit is reached and almost perfect distribution achieved by completely covering the filter with corrugated sheets of metal, the individual troughs being in actual contact. It is with the last group mentioned — pressure and gravity sprinklers — that the present discussion has to deal. Such sprinklers are fixed at definite points at or above the surface of the bed, and are designed to throw the sewage in a spray or spatter over the intermediate areas. The efficiency of their distribution under given conditions of head is determined entirely by their design, and the study of this efficiency is one which lends itself readily to careful experimental methods. The distribution is obviously not a perfect one, if for no other reason than that it is circular, and there must either be overlapping of the circles or intermediate non-wetted spaces, or both. Within each circle, moreover, there is generally a tendency to the formation of concentric rings of greater or less flow than the average, so that if small units of area are studied there will be found a variation in rate of flow along a radius. The definition of perfect distribution is one which is easily grasped, but the conception of a quantitative measure of the unevenness of the distribution is not so simple, and no attempt has heretofore been made to work out such a measure. Obviously the distribution is not measured by the wetted surface, although that expression is the best one which has thus far been used to describe the efficiency of a sprinkler. In the course of an investigation of pressure and gravity sprinklers now being made at this station, the need of some quantitative measure of the [illegible] was at once manifest. A mathematical analysis [illegible] resulting in the definition [illegible] shows the mathematical [illegible] tion and that condition which has [illegible] the [illegible] increasing importance [illegible] this country, it is thought wise [illegible] of the methods of testing employed and of the mathematical analysis of the results. A graphical representation of the conditions of distribution is first worked out, and from it the definition of the "distribution coefficient" is derived.

---

[1] Reprinted from Engineering News of October 18, 1906, LVI, 410–411.

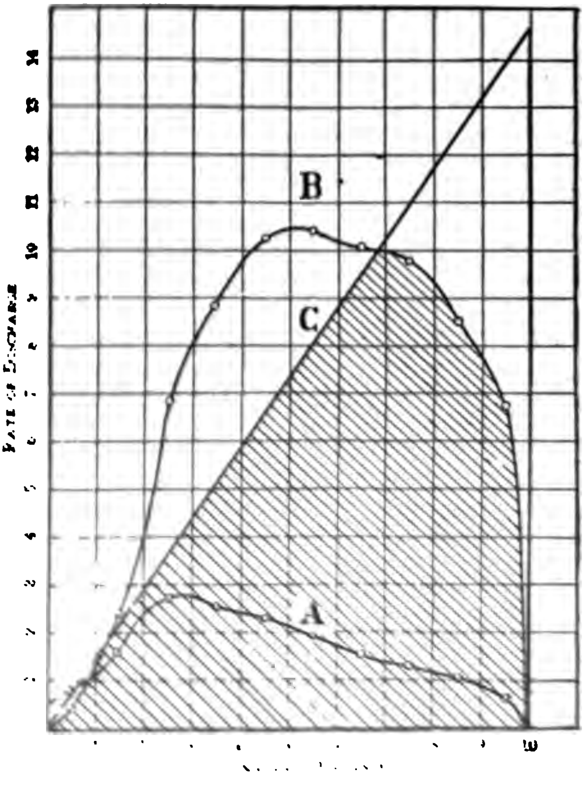
For the purposes of this problem let us assume that a pressure sprinkler is shooting up a spray of sewage, fountain-wise, the sewage falling over a circular area. Along any radius let us place a line of small, square collecting tanks of known areas, which we may designate the unit area. Let it be assumed, further, that the distribution along this radius is the mean of that along all radii. The variations along the various radii will be small, and the assumption may be completely realized, as is being done in our experiments, by revolving the line of collecting tanks about the centre during the experiment. After running a suitable length of time the sewage is shut off and the amount collected in each small tank is measured. In the accompanying table a set of actual results is reproduced for the sake of illustration.

TABLE SHOWING RESULTS OF OBSERVATIONS OF DISTRIBUTION EFFECTED BY SEWAGE SPRINKLER

Tank No.	Radial distance (D).	Sewage quantity (Q).	D × Q.	Excessive Quantities (Ex. Q).	D × Ex. Q.
1	0.5	0.8	0.4	. .	. .
2	1.5	1.6	2.4	0.14	0.21
3	2.5	2.7	6.8	1.24	3.10
4	3.5	2.5	8.8	1.04	3.65
5	4.5	2.3	10.3	0.84	3.78
6	5.5	1.9	10.4	0.44	2.43
7	6.5	1.5	10.0	0.04	0.26
8	7.5	1.3	9.8	. .	. .
9	8.5	1.0	8.5	. .	. .
10	9.5	0.6	5.7	. .	. .
Totals	50.0		73.1		13.43

73.1 ÷ 50.0 = 1.46 = M.

In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being



[illegible] tted as
[illegible] obtain
[illegible] adius.
[illegible] is-
[illegible] re is
[illegible] the
[illegible] dial
[illegible] the

centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i.e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing, relatively, by the radial distance of the point in question. In column 4, D × Q in the table, are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the corresponding D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

From its construction this curve has the following properties: the ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre; the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i.e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter. The base of the triangle is known, and from that and the area its altitude may be computed. It may be calculated more readily but less accurately by adding up the column Q × D and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area, which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the more nearly will the two curves coincide and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves, differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

If we define the term "excessive discharge" as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form,

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities, [illegible] D, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coordinates [illegible] vertical, as usual, and the other set radiating from the [illegible]. Direct plotting of the figures used [illegible] curve A upon [illegible] gives curve B, [illegible] having an actual [illegible] distance [illegible]

W[illegible] under- [illegible] it has [illegible] calcu- [illegible] the [illegible] total [illegible] the total wetted area; that is, it bears the same relation to the total area as the sum of the Q × D column does to the total discharge. Dividing the former by the latter gives the mean discharge (M) per unit area for the whole filter. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in the table under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column, they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total excessive discharge as already defined (E). We have now the two factors T and E for use in the formula,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

In the illustration used,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true coefficient based upon the total area of the filter, portions of which between the circles may not be wetted. Each sprinkler must then be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the final coefficient, C, may be found from the former coefficient, *c*, by the formula,

$$C = c \times \text{Cir}/\text{Sq}.$$

By the use of such a distribution coefficient it is possible to make experimental comparisons of both pressure and gravity sprinklers of various designs, and to test the effects of variations in head, rate of discharge, and other variables upon the distribution.

786 Albany Street, Boston, Mass.

[Reprinted from TECHNOLOGY QUARTERLY, Vol. XX, No. 3, September, 1907]

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND
SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS
INSTITUTE OF TECHNOLOGY

STUDIES OF SEWAGE DISTRIBUTORS FOR TRICKLING FILTERS

BY C.-E. A. WINSLOW, EARLE B. PHELPS, C. F. STORY, AND H. C. MCRAE

I. THE GENERAL PROBLEM OF SEWAGE DISTRIBUTION

THE chief technical difficulty in the construction of the trickling, or percolating filter, as it is called in England, lies in securing efficient distribution of the sewage. The liquid must be discharged slowly and evenly over the whole surface of the bed and thoroughly aërated in the process; in other words, it must be distributed in a rain of fine drops. The mechanism adopted differs widely in various disposal plants. Some of the earlier English investigators used tipping buckets and troughs, placed at intervals over the filter, relying on the splash to dose the intervening areas. This method must necessarily produce imperfect results, and the required apparatus is cumbrous and expensive. Other devices are designed to secure a steady overflow from fixed level troughs or pipes. Of these, the most highly developed is the Stoddart distributor, in use at Horfield and other English towns. This is practically a series of channels over the sides of which the sewage overflows continuously, dripping from points on the under side, 360 points being allowed to a square yard. Theoretically this should secure a very even distribution; but the system requires that the channels remain perfectly level and clean, a condition difficult to preserve in practice.

Another series of distributors secures an even spread of the sewage by the use of some form of moving apparatus. The simplest devices of this type consist of a pair of revolving arms discharging sewage in opposite tangential directions, so that they are propelled by their own discharge on the principle of a Barker mill. The Candy-Whittaker patents cover some of the best known English distributors of this type. More elaborate designs involve the use of power for moving troughs from which the sewage trickles by numerous small openings, or from which it flows in a thin stream over a weir. In connection with the experiments carried out at Birmingham, Scott-Moncrieff installed a large distributor of this pattern, which consisted of a trough revolving on a circular rail at its outer extremity and driven by a small oil engine. At Hanley is a similar trough, which runs back and forth over a rectangular bed, propelled by an electric motor.

There are certain inherent objections to all such movable distributors which have so far seemed almost insuperable to American engineers. Power, or its equivalent hydraulic head, is necessarily involved in all of them. Movable arms and troughs involve structural details which are expensive to construct and which require constant attention; and it may seriously be doubted whether devices of such complexity and delicacy of adjustment could be operated at all under the influence of a severe winter climate. Even in England trouble was experienced at certain plants during the cold winter of 1906–07.

The simplest and most practical of the English methods of distribution is the system of spraying the sewage upward from sprinkler heads arranged at intervals along fixed pipes. Fixed sprinklers of this type have been used for some time at Salford and other English towns, and are planned for the two largest trickling filter plants yet designed in the United States — at Columbus, Ohio, and Waterbury, Connecticut.

The chance of offensive odors is of course increased by the distribution of sewage spray in the air, but the free oxidation probably facilitates purification. At Birmingham a careful comparison has been made of various types of revolving distributors and pressure nozzles. Mr. J. D. Watson reports (*Engineering News*, 58, 89), as a result of these studies, that spray jets cost $2,500 per acre to install, against $5,000 to $20,000 for moving distributors, and that the beds equipped with the latter were idle as a result of the distributor being out of order from 8 to 28 per cent. of the time. The results obtained with fixed sprinkler heads of course depend largely on the details of their construction, the head available, the spacing of the nozzles, and particularly on the construction of the nozzles themselves.

In the course of the investigations on the purification of the sewage of Boston, carried out at the Sanitary Research Laboratory of the

Massachusetts Institute of Technology, another method, that of gravity distribution, has been devised.

This system, referred to in an address before the Society of Arts, October 12, 1905, and described in the *Engineering News* for August 16, 1906, appears to possess certain distinct advantages. The sewage is distributed in troughs elevated over the filter, from which it drops through holes in the bottom of the troughs onto concave disks below, splashing upward from the disks in a fine spray. It has been used for two years with success at the Boston station, and has since been adopted by the Massachusetts State Board of Health for an experimental filter at Andover, according to an account published in the *Engineering News* of April 11, 1907.

With distributors of almost any type it is possible to combine siphon tanks or other automatic devices for securing intermittency of operation. The increased pressure thus produced at the moment of maximum discharge tends to keep clear any openings which might otherwise clog, and when the sewage is discharged under pressure from perforated pipes the variations in head tend to make the circle of spray both wider and more even. This plan has long been used at Chesterfield and other English towns.

II. METHODS FOR MEASURING THE EFFICIENCY OF SEWAGE DISTRIBUTORS

The Stoddart distributor and the various types of movable sprinklers used in England are theoretically perfect, and their failure, when it occurs, is due to structural imperfections or lack of care in maintenance. On the other hand, fixed sprinkler nozzles and the gravity system of distribution cover at best only a portion of the surface of the filter. Since both these latter types discharge sewage approximately in a circle, each nozzle or disk will wet only 78 per cent. of the square area surrounding it. Furthermore, almost all these distributors tend to discharge, for the most part, in one or two concentric rings of the wetted area. Some nozzles, too, discharge unevenly along different radii. It is important to determine how serious these deviations are. Imperfect distribution means that a part of the filter area below is wasted and another part is operated at excessive rates. Yet almost no exact data upon this point are now available. Some experimenters have noted the proportion of the total area wetted by their sprinklers; but such a standard is, of course, wholly inadequate, since it fails to discriminate the extent of the discharge upon different portions of the wetted area. We have therefore thought it worth while to make a somewhat extensive study of this point, comparing in detail the efficiency of various fixed sprinkler nozzles and of a number of patterns of gravity distributors under various conditions.

For the quantitative study of the efficiency of distribution a measuring apparatus was devised, the construction of which is indicated in Figures 1 and 2. It consisted of a shallow, circular basin of cement concrete 14 feet in diameter, sloping toward a central drain connected with a waste pipe below. A 2-inch supply pipe passed under the concrete and rose through [illegible] the basin. To this pipe were attached the sprinkler nozzles of various types designed for pressure distribution. A wooden tray in the shape of the 30° sector of a circle was attached at its [illegible] a 2½-inch

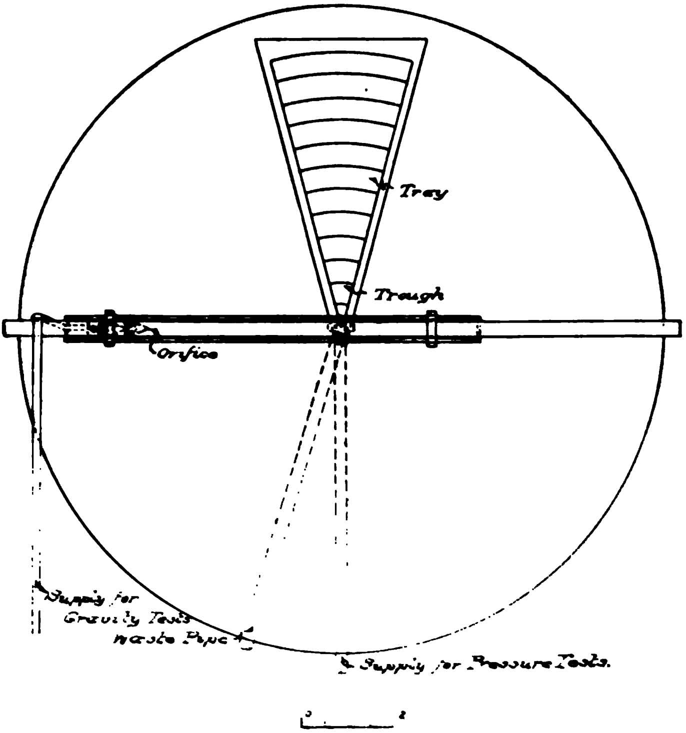


FIG. 1. PLAN OF APPARATUS FOR SPRINKLER TESTS

iron collar, fitted over the supply pipe so as to turn freely upon it. The outer end of the wooden platform was supported on ball-bearing castors, arranged to run on a flat shelf at the periphery of the concrete basin, so that the whole platform could be revolved about the supply pipe as a centre; and the collar and castors were so adjusted that the platform was exactly level. The platform carried a galvanized iron tank, also in the form of a 30° sector, divided into compartments by concentric arcs 6 inches apart. The radius of the tank was 6 feet, giving twelve concentric compartments, and its depth was 6 inches. When this tank was rotated about the supply pipe during the course of an experiment, the evenness of distribution was of course measured by the

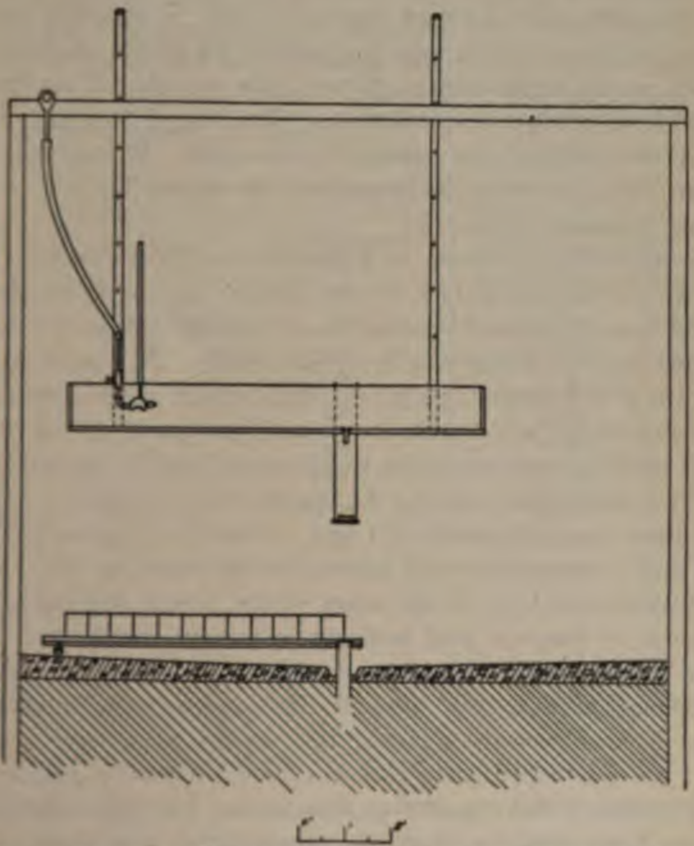


Fig. 2.—Sectional Elevation of Apparatus for Sprinkler Tests

relative amount of liquid collected in the respective compartments. In various stationary positions the trough recorded radial inequalities.

The supply pipe at the centre of the basin was connected at its outer end with an upright stack of 2-inch pipe made up of short lengths, any desired number of which could be used. At the top of the stack was a wooden box, fed by a hose and relieved by an overflow just below the top. The difference between the water level in this box (varied by removing sections of pipe from the upright stack) and the level of the sprinkler nozzle at the centre of the basin represented approximately the total head effective in distribution. The rate of flow was of course fixed by the head and the sprinkler nozzle used. It was estimated in [illegible] the discharge into the measuring tank, and from [illegible]

[illegible] shown in Figures [illegible] and 2 was adapted for the [illegible] distributors by the addition of an overhead trough. [illegible] timbers passing diametrically across the basin, [illegible] extremities by upright st[illegible]. At a point fixed over [illegible] brass [illegible] in the bottom of the [illegible] discharge upon the splashing disk below.

The upright [illegible] the trough were fixed to the cross-timbers [illegible] for the recep- [illegible] distance between the [illegible] at will. The dis- [illegible] the top of the [illegible] In this [illegible] total head, [illegible] splashing disk [illegible] be mutually [illegible] supporting the [illegible] 6.5 inches in diameter [illegible] wires. Varying [illegible] the total head above the [illegible] "head on sprinkler").

[illegible] distributor is, within limits, [illegible] had to be taken into account. [illegible] equal to the rate of supply of [illegible] through a calibrated [illegible] orifices were used in the experi- [illegible] inch in diameter. The orifice plug in use was connected to a 2-inch tee by a reducing coupling. The section of the tee was large enough to permit an accurate measurement of the static head on the orifice by a glass piezometer tube inserted in its top, and the head was adjusted at any desired point by a valve behind the tee.

The orifices were calibrated by measuring their discharge at various heads in a cypress tank, 2 feet by 6 feet in area and 3 feet deep. A special form of gauge, to be described later, was used in these measurements, and they were accurate within .005 inch in the depth of the tank, or .005 cubic foot of discharge. The calibration of the $\frac{7}{16}$-inch orifice is shown in Table I.

TABLE I—CALIBRATION OF ORIFICE

Head on $\frac{7}{16}$-inch orifice.	Q in cubic feet per minute.	Q in gallons per minute.
Inches.		
5	.228	1.71
6	.240	1.80
7	.256	1.91
8	.276	2.06
9	.289	2.16
10	.306	2.29
12	.330	2.47
14	.354	2.65
16	.378	2.83
18	.400	3.00
20	.420	3.15
22	.438	3.28
25	.468	3.50
36	.546	4.08

The discharges of 1.71 and 4.08 gallons per minute, corresponding to 5-inch and 36-inch heads on the orifice, were chosen as two arbitrary rates of discharge for the gravity distributor tests. The $\frac{5}{8}$-inch orifice was tested sufficiently to find a third, higher rate. A head of 18 inches on this orifice was found to give a discharge of 1.1325 cubic feet, or 8.47 gallons per minute, and this was used as the standard rate for high discharges. The entire apparatus was protected during the course of the experiments by a rough wind shield.

The measurement of the volume of liquid collected in the various compartments of the measuring tank during a test was, according to our original plans, to be made directly, and for this purpose a small stopcock was attached to each compartment. This process proved somewhat tedious, however, and the same end was attained by measuring the depth of the liquid in each compartment at the end of the run, after a careful preliminary calibration of the various compartments.

The depth of water in this measuring tank, and in the cypress tank used for nozzle calibration, was measured by a simple and accurate gauge devised for the purpose, the construction of which is indicated in Figure 3. It consisted of a graduated glass tube (a 1 c.c. pipette), the graduated portion being 6 inches long and divided into hundredths. This tube slid up and down in a cork fitted into a long, flat piece of wood, carefully planed. When the wooden crosspiece rested in a horizontal position, supported at its ends, the tube between was exactly vertical. Just above the wooden crosspiece a fine wire was stretched longitudinally between two supports behind the tube, and behind the wire a small mirror was fixed. By reading with the wire and its reflection superposed the position of the tube could be estimated to tenths of its smallest graduations (.0005 foot). In measur-

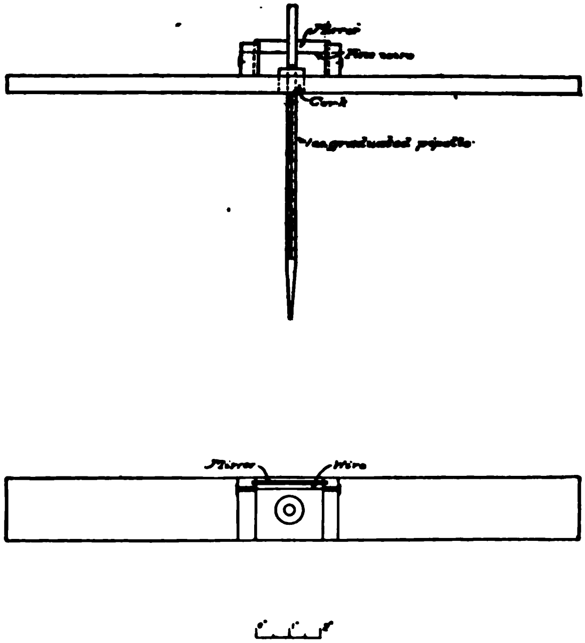


FIG. 3.—ELEVATION AND PLAN OF GAUGE

ing the depth of water in a compartment of the measuring tank the wooden crosspiece of the gauge was rested on the two sides of the tank and the tube was slid carefully down till its mouth just touched the surface of the water. This point could be detected with great accuracy by the jump into the tube of the drop of water drawn up by capillary action.

Each compartment of the measuring tank was calibrated by pouring in measured quantities of water and reading the depth after the addition of each successive portion. The average of these determinations gave the number of units of depth corresponding to a given volume of water. The reciprocal of this was the volume of water corresponding to a unit of depth for the compartment in question. A special correction was necessary for irregularities in the bottom of the tank and for the zero reading of the gauge. The former was determined by the difference between the change in level produced by the first portion of water poured in and by subsequent portions. The general results of this tank calibration are indicated in Table II.

TABLE II — CALIBRATION OF MEASURING TANK

Compartment.	Change in depth for one liter added.*	Bottom correction.	Liters per unit change in depth.†	Gallons per unit change in depth.	Relative value (area).
1	.268	+.020	.933	.246	1.0
2	.187	. .	2.674	.706	2.87
3	.220	—.017	4.545	1.209	4.92
4	.158	—.009	6.329	1.67	6.80
5	.120	—.008	8.333	2.20	8.96
6	.101	—.017	9.901	2.61	10.6
7	.084	—.017	11.90	3.14	12.8
8	.074	. .	13.51	3.57	14.6
9	.065	—.015	15.38	4.06	16.6
10	.059	—.014	16.95	4.47	18.2
11	.052	—.027	19.23	5.08	20.7
12	.048	—.013	20.83	5.51	22.4

* Half a liter for compartment No. 2; quarter of a liter for compartment No. 1.
† Unit = .5 foot.

The "relative values" in the last column of the table should, of course, have come out 1, 3, 5, 7, etc., if there had been no irregularities in the construction of the tank, for with unit depth:

$$Q_1 = \frac{\pi \times 1^2}{4} \times 1 = \frac{\pi}{4}$$

$$Q_2 = \frac{\pi \times 2^2 \times 1}{4} - \left(\frac{\pi \times 1^2}{4} \times 1\right) = \frac{3\pi}{4} = 3Q_1.$$

$$Q_3 = \frac{\pi \times 3^2 \times 1}{4} - \left(\frac{\pi \times 2^2}{4} \times 1\right) = \frac{5\pi}{4} = 5Q_1.$$

The testing apparatus in operation is shown in Figure 4, and nearer views of the measuring tank in Figures 5 and 6. The following memorandum of the routine procedure in making the test of a gravity distributor may make the working of the whole apparatus somewhat clearer. In beginning a run the measuring tank was emptied, put in place on the wooden platform, and covered with a cover of tar paper stretched over slats. The desired total head was adjusted by raising or lowering the trough, and the head on the sprinkler was regulated by means of the wires suspending the lead plate from the trough. The disk to be tested was then centred on the lead plate just below the ¾-inch opening in the bottom of the trough. The valve supplying the trough was then opened and regulated till the desired discharge was registered on the

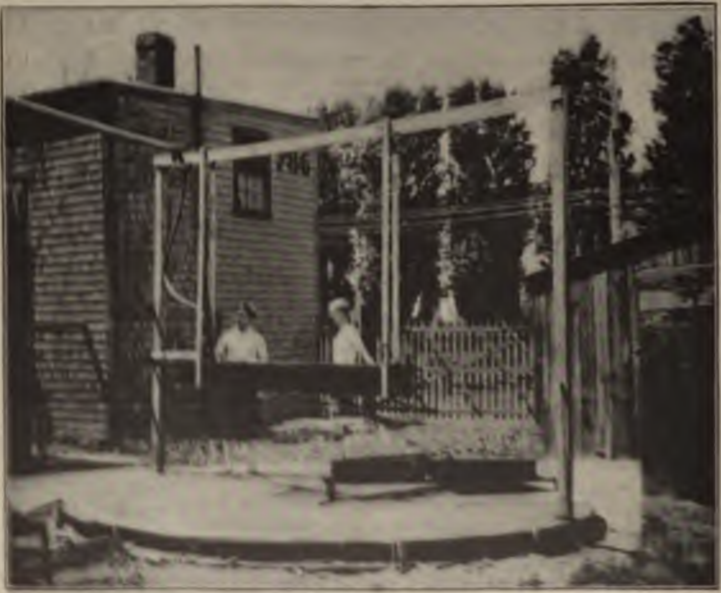


FIG. 4—GENERAL VIEW OF TESTING APPARATUS WITH TEST IN PROGRESS

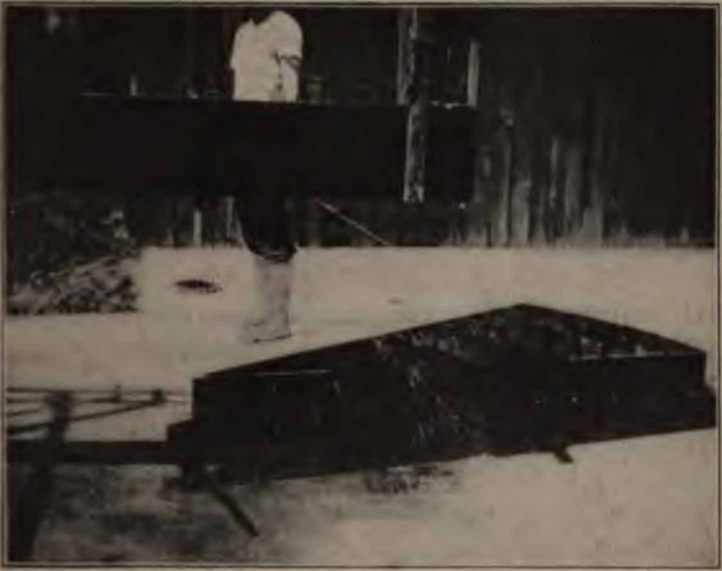


FIG. 5.—SIDE VIEW OF MEASURING TRAY WITH TEST IN PROGRESS, SHOWING TROUGH AND DISTRIBUTING DISK IN PLACE

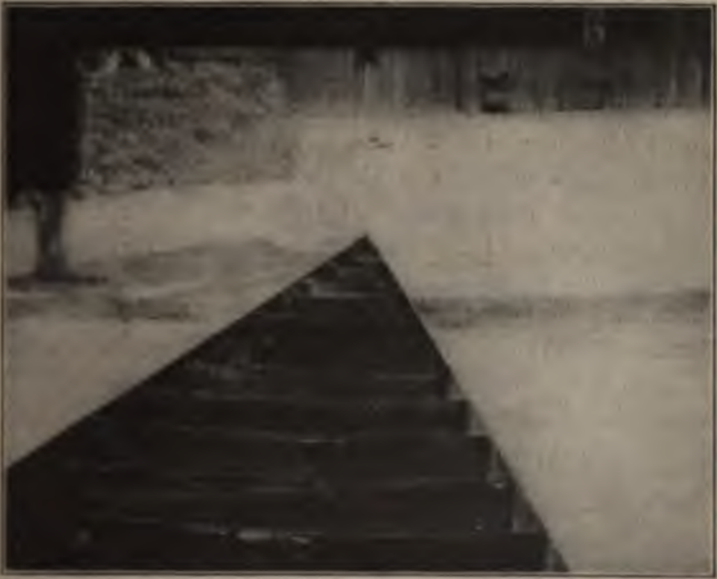


FIG. 6.—VIEW OF MEASURING TRAY FROM ABOVE. TEST IN PROGRESS

piezometer tube. After conditions had become constant in the trough, the cover of the measuring tank was removed (the time being taken with a stop watch). During the test the tank was slowly rotated by hand. As soon as any compartments became so full as to threaten splashing the test was stopped, the cover replaced, and the time again noted. The supply valve was then closed, and after the discharge had ceased the cover was removed and the depth of liquid in each compartment of the measuring tank was determined, as described above.

III. METHOD OF CALCULATING A COEFFICIENT FOR THE EFFICIENCY OF SEWAGE DISTRIBUTORS

After the proportionate amount of discharge in various zones about the distributors had been determined by the method outlined above, it was necessary to devise some method of stating the results so that the efficiency of the various types could be easily and accurately compared. For this purpose one of us (E. B. P.) has derived a "coefficient of distribution," which shows the mathematical relation between any observed condition of distribution and that ideal condition in which each unit of area should receive its exact proportionate share. [illegible] were published in the *Engineering News* [illegible] March [illegible]

[illegible] pressure [illegible] sewage [illegible]

TABLE III—RESULTS OF OBSERVATIONS OF DISTRIBUTION EFFECTED BY SEWAGE SPRINKLER

Tank No.	Radial distance (D).	Sewage quantity (Q).	D × Q.	Excessive quantities (Ex. Q).	D × Ex. Q.
1	0.5	0.8	0.4	. .	. .
2	1.5	1.6	2.4	0.14	0.21
3	2.5	2.7	6.8	1.24	3.10
4	3.5	2.5	8.8	1.04	3.65
5	4.5	2.3	10.3	0.84	3.78
6	5.5	1.9	10.4	0.44	2.43
7	6.5	1.5	10.0	0.04	0.26
8	7.5	1.3	9.8	. .	. .
9	8.5	1.0	8.5	. .	. .
10	9.5	0.6	5.7	. .	. .
Totals	50.0		73.1		13.43

$73.1 \div 50.0 = 1.46 = M.$

"In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being proportional to the volumes. Now if these quantities, Q, are plotted as ordinates against the corresponding D values as abscissæ, we obtain a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram (Fig. 7). It shows the rate of discharge per unit area at any point whose distance from the centre is known, and will be known as the curve of radial distribution. Since the radial distribution measured was assumed to be the mean of all radial distributions, the ordinate of this curve at any given distance from the centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i. e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing, relatively, by the radial distance of the point in question. In column 4, $D \times Q$, in the table are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the corresponding D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

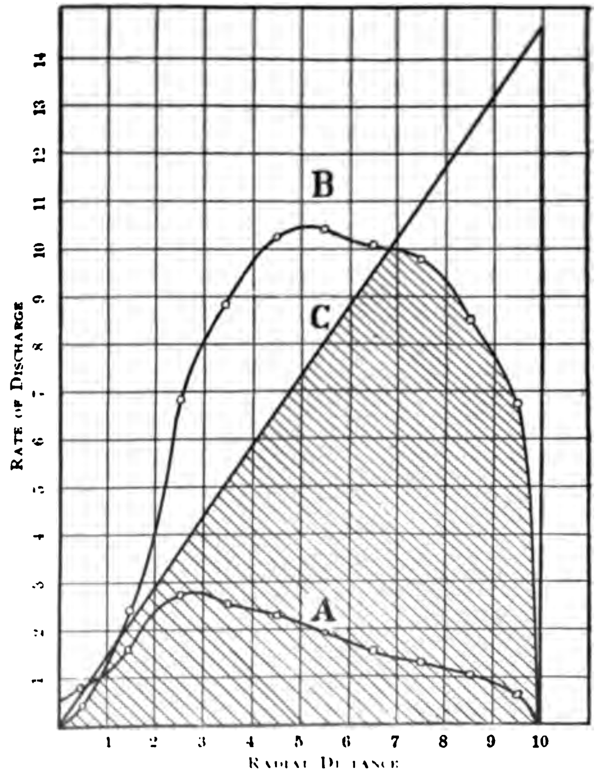


Fig. 7.—Diagram of Distribution

A. Curve of radial distribution. B. Curve of distribution over the circle. C. Curve of perfect distribution over the circle.

"From its construction this curve has the following properties: The ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre;

the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

"It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i.e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter, and from the known base of the triangle its altitude may be computed. It may be calculated more readily but less accurately by adding up the column Q × D, and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

"We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the more nearly will the two curves coincide, and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

"If we define the term 'excessive discharge' as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form.

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or, more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

"Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities Q × D, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coördinate lines vertical, as usual, and the other set radiating from the origin. Direct plotting of the figures used in curve A upon such paper will in reality give curve B, any given value having an actual magnitude upon the plot which is proportional to the horizontal distance from the origin."

While the plot and the foregoing demonstration are essential to a clear understanding of the coefficient, it has been found much simpler and sufficiently accurate in practice to make an arithmetical calculation of the coefficient directly from the observed data. Either of the last two columns in Table II may be used instead of column 2, D, in Table III, since it corresponds to it with an allowance for the irregularities of construction in the tank. For column 3, Q, the observed depth is used, after the application of the proper bottom correction. The sum of the fourth column, D × Q, gives the total discharge, T, upon the sector tested, directly in gallons, if the relative value in gallons is used for D. The sum of column 2, D, corresponds to the total wetted area; that is, it bears the same relation to the total area that the sum of the fourth column, D × Q, does to the total discharge. In practice, when the liquid discharged did not reach the outer compartments, those zones not wetted were of course omitted from column 2. Now if the sum of column 4, D × Q, be divided by the sum of column 2, D, the quotient, M, will be the mean discharge per unit area over the whole wetted surface. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in Table III in column 5, under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total excessive discharge as already defined, E. In practice, the difference between the mean discharge and the actual discharge was also determined for the zones which received less than their share; and the sum of these values was used as a check on the total excessive discharge, E.

Either the total excessive discharge on the areas receiving too much liquid, or the total deficient discharge on the areas receiving too little, when divided by the total discharge measures the deviation of the distribution from a perfect condition. Referring to Figure 7, it will be seen that the total discharge, T, corresponds to the area under the line C, and that the excessive discharge, E, corresponds to the area below B and above C. Perfect distribution would be indicated by a value of zero for E or a coincidence of lines B and C. This condition is called unity, and the observed condition in any case is expressed as the difference between unity and the ratio of excessive discharge to total discharge. In the shape of a formula this becomes,

$$\text{Dist. Coef.} = 1 - \frac{E}{T},$$

and in the illustrative example given in Table III,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The crude coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true corrected coefficient based upon the total area of the filter, including the unwetted corners between the circles. Each wetted area should be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the corrected coefficient, C, may be found from the crude coefficient, *c*, by the formula,

$$C = c \times \text{Cir}/\text{Sq}.$$

This correction will, of course, diminish the crude coefficients to less than 78 per cent. of their value for the wetted area, and all coefficients recorded in our investigation are calculated upon this basis of arrangement in squares. In practice, however, it would be of advantage to arrange distributors, not along two axes at right angles to each other, so that each is at the centre of a square, but on three axes inclined at 120°, so that each is at the centre of a hexagon. With distributors at the centres of squares, the waste area, with no overlapping, amounts to 21.5 per cent. of the whole. With distributors at the centres of hexagons, the waste area amounts to only 9.9 per cent. The hexagonal arrangement makes it possible to put 343 sprinkler heads on an acre instead of 303, spaced with 12 feet between centres, and to raise a rate of 2,000,000 gallons to 2,270,000 without increasing the discharge upon any portion of the wetted area.

IV. DETERMINATION OF COEFFICIENTS FOR GRAVITY DISTRIBUTORS

The system of gravity distribution involves the discharge of the sewage from openings in the bottom of troughs onto concave disks placed below, the discharged stream having sufficient force to splash up and out from the disks in a fine spray.

The splashing disks first used on the Technology trickling filter in 1905 were of metal, 3 inches in diameter, and with a concavity corresponding to a radius of curvature of 6 inches. These were at first placed only 5 feet apart, with a discharge on each disk of less than .9 gallon per minute. This discharge proved too low for good distribution, and a single disk was substituted for four on each 100 square feet in area, giving 10 feet between disks and a discharge on each of 3.47 gallons per minute. This proved far more satisfactory, and the experimental filter thus equipped gave very satisfactory results even through the severe winter of 1906-07. The performance of one of these disks in operation is shown in Figure 8.

With gravity distributors there are three distinct variable factors, the rate of discharge, the distance between the trough and the disk, and the distance between the disk and the filter below. In our experiments we have varied all three independently. For rates we have used the three standard discharges described above, corresponding, respectively, to 1.71, 4.08, and 8.47 gallons per minute. For the total head between the trough and the measuring tank (corresponding to the filter surface) three standard heads were used, 2 feet, 4 feet, and 6 feet; and with each of these total heads three different positions of the disk were tested. With the 2-foot total head the head-on-sprinkler was made 6 inches, 12 inches, and 18 inches; with the 4-foot total head the head-on sprinkler was made 1, 2, and 3 feet; with the 6-foot total head the disk was placed at 1, 2½, and 4 feet.

Besides these three variable factors the efficiency of gravity distribution depends upon the design of the splashing disks themselves.

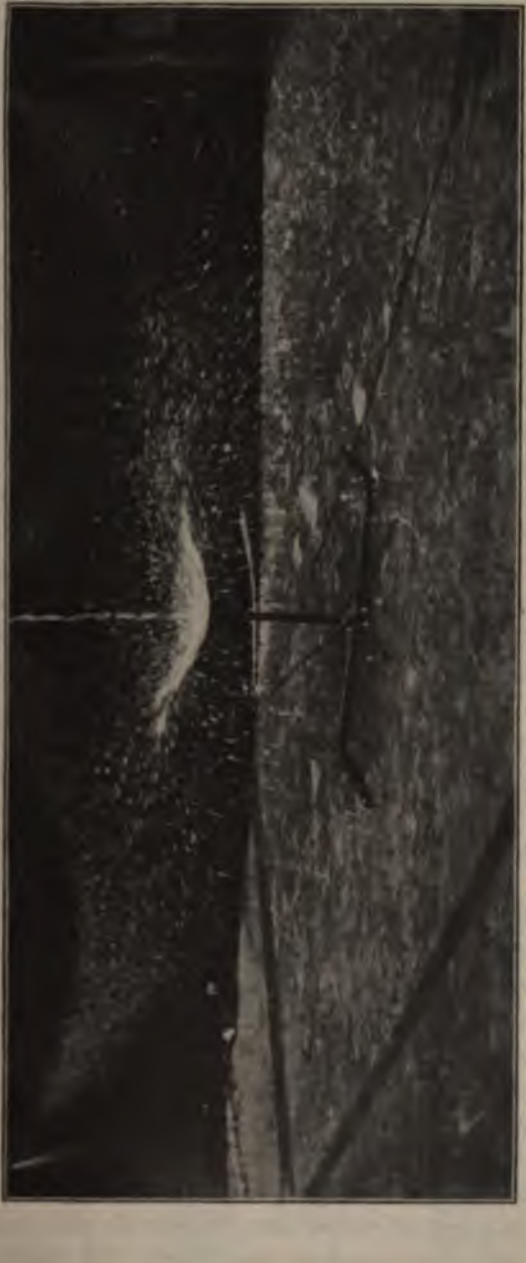


Fig. 8.—View of Gravity Distributor in Operation

Twenty-three types of disks were tested in our experiments, varying in size and curvature, in the hope of finding some more favorable design than the simple concave type first used. Cross-sections of the disks examined, with their respective dimensions, are shown in Figure 9.

Nos. 1 to 4 were wooden disks 2 inches in diameter, with surfaces of different degrees of concavity varying from a radius of curvature of 4 inches to one of 20 inches. Nos. 5 to 10 were disks 3 inches in diameter, Nos. 6 and 7 of metal and the rest of wood, the radii of curvature of their concave surfaces varying from 2 to 20 inches. Nos. 11, 12, and 16 were larger, very shallow wooden disks. Nos. 13, 14, 17, 18, and 19 were wooden disks whose upper surfaces were concave about a central raised point, rising again all around their outer edge. We have called this design the mushroom disk. No. 15 was a large, deep metal disk, 5 inches in diameter, and with a 3-inch radius of curvature. Finally, Nos. 20, 21, 22, and 23 were large, 6-inch wooden disks with radii of curvature varying from 4 to 20 inches.

Since each of these twenty-three disks was tested under twenty-seven standard conditions (three subdivisions of each of three total heads at three rates), making over six hundred tests in all, it has not seemed best to publish the mass of figures obtained in detail. The final corrected coefficients are given in Tables IV, V, and VI, arranged first according to the rate of discharge on each disk and then according to the head.

It must be remembered, of course, that the corrected coefficients in these tables take account both of the extent and the evenness of the area of spray. Some of the disks produced good distribution within a small [illegible] but the rate on the wetted area was so great as to be excessive. By reducing the crude coefficients for such disks so as to bring the total rate [illegible] to 2,000,000 gallons per acre per day, the corrected coefficients have been estimated. This was done for the three rates of discharge tested as follows. A discharge of [illegible] gallons per minute on each square [illegible] disk corresponds to [illegible] gallons per day per disk [illegible] per acre, or [illegible] between sprinklers [illegible] gallon rate would require [illegible] square feet, and the distance between [illegible] gallon rate [illegible] feet, with a distance [illegible] the

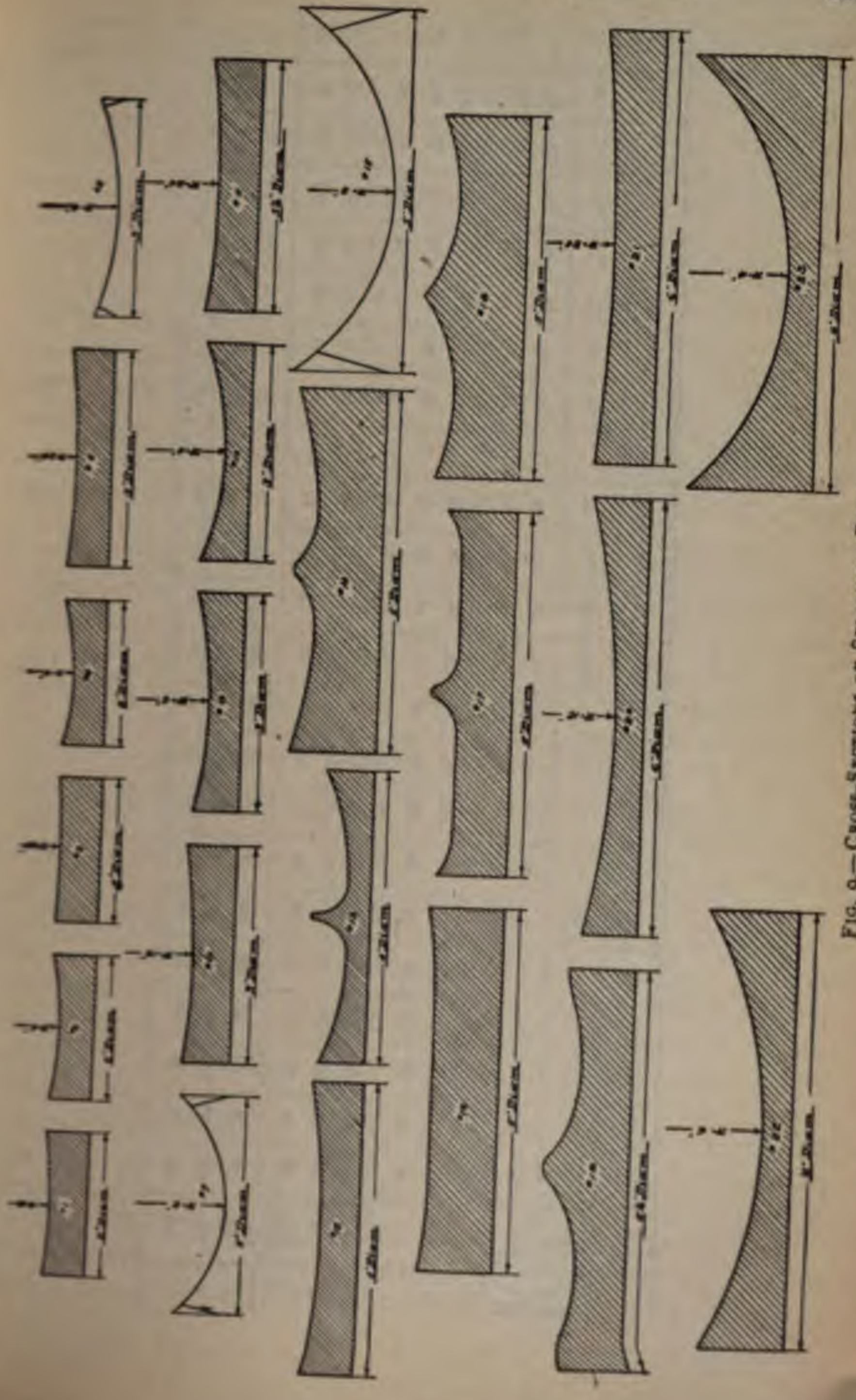


Fig. 9.—Cross-Sections of Splashing Disks

[illegible] FOR GRAVITY DISTRIBUTORS

[illegible] – 2,000,000 gallons per acre per day

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	11	12	13	14	15	16	17	18	19	20	21	22	23
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.	.02	.02	. .	. .	.02	. .	. .	. .	. .	. .	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	. .	.04	. .	.05	. .	.01	.04	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	. .	.03	.06	.06	.02	. .	.03	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.16	.17	.17	.16	. .	.15	.11	.10	.06	.08	.09	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.10	.17	.17	. .	.08	.10	.17	.05	.05	.04	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.16	.16	.16	.15	. .	.08	.13	.15	.10	.01	.01	.01	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.14	.16	.27	.20	. .	.10	.17	.21	.09	.04	.06	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.37	.20	. .	.26	.31	.38	.17	.09	.04	. .	. .
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.10	.18	.40	.28	. .	.14	.23	.37	.16	.07	.10	.12	. .

TABLE V—CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 4.08 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

Total head in feet.	Head-on-sprinkler, feet.	NUMBER OF DISK.																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	0.5	.05	.05	.04	.05	.05	.05	.05	.04	.05	.05	.04	.05	.05	.03	. .	.05	. .	. .	.02	.03	.03	.02	. .
	1.0	.08	.07	.07	.08	.05	.08	.11	.08	.08	.09	.04	.06	.09	.10	.04	.09	.08	.09	.05	.06	.05	.06	. .
	1.5	.08	.08	.06	.07	.05	.11	.09	.08	.08	. .	.05	.08	.09	.09	.06	.09	.09	.09	.05	.06	.06	.08	.04
4	1.0	.20	.17	.17	.18	.15	.22	.20	.17	.17	.22	.15	.19	.18	.16	.09	.18	.18	.15	.07	.16	.13	.13	. .
	2.0	.24	.25	.23	.31	.18	.35	.32	.19	.26	.30	.17	.21	.28	.27	.09	.20	.20	.27	.10	.15	.09	.18	.10
	3.0	.19	.17	.18	.25	.16	.26	.40	.18	.18	.31	.17	.20	.26	.31	.14	.18	.27	.20	.13	.12	.11	.17	.09
6	1.0	.30	.29	.25	.30	.24	.26	.24	.25	.26	.24	.23	.26	.27	.25	. .	.25	.26	.29	.25	.19	.17	.18	. .
	2.5	.26	.46	.38	.51	.38	.50	.60	.41	.40	.42	.33	.36	.57	.54	.20	.21	.35	.37	.27	.27	.22	.18	.11
	4.0	.36	.38	.28	.44	.31	.56	.62	.36	.42	.44	.26	.32	.46	.45	.25	.30	.30	.33	.35	.25	.18	.24	.14

[illegible] COEFFICIENTS FOR GRAVITY DISTRIBUTORS

[illegible] —2,000,000 gallons per acre per day

Number of [illegible]

						11	12	13	14	15	16	17	18	19	20	21	22	23
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.03	.04	.03	.04	.02	.04	.04	.04	.04	.04	.04	.03	.03
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.04	.06	.07	.07	.06	.07	.07	.06	.04	.05	.04	.05	.04
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.05	.06	.10	.10	.07	.07	.10	.08	.04	.05	.05	.06	.06
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.12	.16	.16	.16	.09	.14	.16	.17	.09	.12	.11	.10	.09
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		.10	.12	.20	.19	.11	.15	.18	.19	.12	.12	.10	.18	.09
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		.10	.18	.23	.24	.13	.13	.20	.16	.09	.12	.10	.18	.09
		[illegible]	[illegible]	[illegible]		.14	.17	.20	.19	.12	.15	.18	.18	.14	.18	.18	.18	.10
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.17	.20	.26	.20	.17	.20	.28	.30	.25	.30	.30	.22	.18
[illegible]		[illegible]	[illegible]	[illegible]		.14	.22	.22	. .	.19	.20	. .	. .	. .	.18	.18	.18	.14

tables have therefore been corrected by referring the actual discharges to squares respectively 7.35, 11.3, and 16.3 feet on a side.

Taking up the independent variables tested in their order it is at once apparent that the efficiency of gravity distributors is markedly influenced by the rate of discharge on each disk, and that about 4 gallons a minute is the most favorable rate. The lower rate, 1.7 gallons per minute, gave very poor results with the larger disks, the liquid merely dripping over the edge. With the smaller disks fairly good results were obtained within a radius of 3 or 4 feet of the disk, although there was generally an excess of discharge nearest the centre. As the distance between sprinklers for this head was only 7.35 feet, the crude coefficients of .6 and .7 were not so greatly reduced as in other cases, and for the smallest (2-inch) disks this rate is better than either of the higher ones. Most of the 2-inch disks gave corrected coefficients of over .4 even with the 6-foot total head, and coefficients of over .5 were obtained for disks 4, 6, and 10.

The intermediate rate of 4.08 gallons per disk per minute did not suit the small, 2-inch disks as well as the lower rate, but with larger disks it gave better results. With good heads the liquid was well distributed, showing neither the concentration near the disk obtained with the lowest rate nor the marked outer ring characteristic of the higher one. Crude coefficients of over .7 were obtained with almost all the disks by using a 6-foot head, and the better ones ranged between .8 and .9. Furthermore, the wetted area was proportionately larger than with the higher or the lower rate of discharge; 4.08 gallons per disk per minute calls for a distance of 11.3 feet between sprinklers, and with high heads the better disks wetted circles 10 and 11 feet in diameter. The corrected coefficients remained, therefore, relatively high, several of the disks showing values over .5, and one, disk No. 7, over .6.

With the highest rate the better disks covered a 10-foot circle, but there was usually a ring of excessive discharge at a distance of 3 or 4 feet from the centre. The larger disks, at high heads, gave crude coefficients of between .7 and .8, wetting a circle of 6 feet radius. Corrected for a 16.3-foot square these crude coefficients are seriously reduced, only two of the corrected coefficients in Table VI being over .3.

The head used with the sprinkler disks was a most important factor in controlling their efficiency. The 2-foot total head proved inadequate in most cases. Some of the crude coefficients were fairly good (between .6 and .8); but the wetted area was always much too

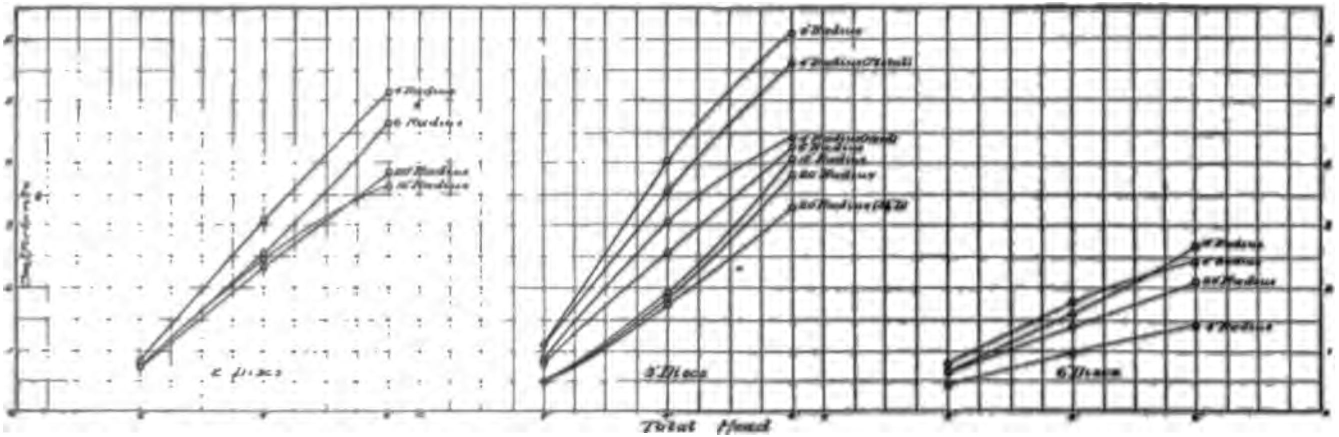


FIG. 16.—RELATION BETWEEN TOTAL HEADS AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE
Rate — 4.08 gallons per minute. Best head-on-sprinkler in each case.

small, giving an excessive rate near the sprinkler, and the corrected coefficients were almost always under .1. The 4-foot total head showed better results, and the 6-foot better still, the improved efficiency being directly proportional to the increase in head. This relation is indicated graphically in Figure 10 for the disks of 2, 3, and 6-inch diameters at the best rate of 4.08 gallons per disk per minute. The total heads are plotted as abscissæ and the best coefficients at the different total heads as ordinates. Each curve represents the results for one sprinkler disk, and the fifteen curves are arranged in three groups according to their diameters. The radius of curvature of each disk is indicated on the plot.

With regard to the best proportion of the total head to be used in the discharge above the disk, results are somewhat more variable. Increasing the head on the disk gives an enlargement of the wetted area, but it apparently brings about also an increased tendency to concentrated discharge in a single zone. The figures for the intermediate rate and 6-foot total head at the bottom of Table V include the best coefficients, and are fairly typical of the other results. They show that with a 6-foot total head a head-on-sprinkler of 2½ feet is most favorable for the shallower sprinklers, and a value of 4 feet is better for the deeper ones. The 1-foot head-on-sprinkler is always inadequate to secure a proper splashing discharge. These results are indicated with greater clearness in Figure 11, where the coefficients for the best rate (4.08 gallons per minute) and best total head (6 feet) are plotted for the three values of head-on-sprinkler which were tested. The curves on the diagram otherwise correspond to those of Figure 10. The dimensions of each disk are indicated in Figure 9.

There remains still to be considered the influence of the shape of the splashing disk itself. Two general patterns were studied — simple concave plates and disks of the "mushroom type" with a raised central cone (Nos. 13, 14, 17, 18, and 19). The latter show coefficients intermediate between the large and small concave disks, better than the former and not so good as the latter. In other words, the slope on one side of the central boss deflects the water very much as a simple cup of similar size and curvature would do. The discharge from these disks was, however, unequal along different radii, since it was almost impossible to make the stream of liquid strike the central boss. The coefficients are therefore higher than they should be, since the revolving trough caught portions of unequal discharges in

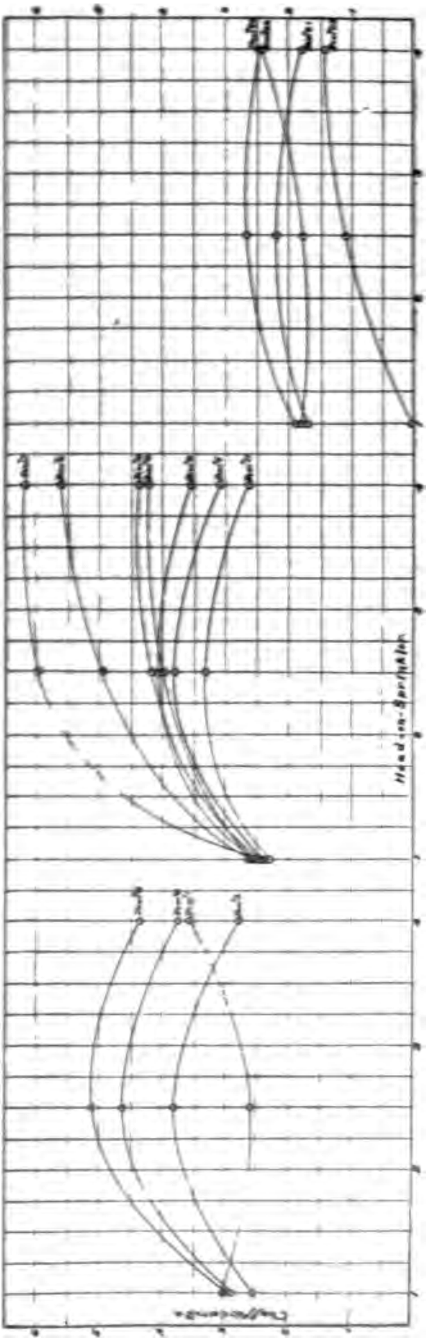


FIG. 11.—RELATION BETWEEN HEAD ON SPRINKLER AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE
Rate = 4.08 gallons per minute. Total head = 6 feet.

different zones along the various radii. There seems to be no advantage in the use of disks of this pattern.

There remain the simple concave plates, varying in diameter and in radius of curvature. For diameter, 3 inches is clearly the most favorable size. A comparison of the three sets of curves in Figure 10 shows that the 3-inch disks (Nos. 5, 6, 7, 8, 9, and 10) are better than the 2-inch disks (Nos. 1, 2, 3, and 4), and far superior to the larger ones (Nos. 20, 21, 22, and 23). These figures, it must be remembered, relate to the 4.08-gallon discharge. At the lower rate (1.71 gallons per disk per minute) the 2-inch disks give higher coefficients than the 3-inch ones. This might be expected, since poor distribution with large disks arises from the fact that the liquid has not force enough to splash freely off, but pools and drips over the edge. The smallest disks are therefore best suited to low discharges, but the 3-inch disks and 4.08-gallon rate form the best combination.

The effect of varying radius of curvature is well shown in Figure 10 for the 4.08-gallon rate; and the constancy of the relation is indicated by the comparison made in Table VII.

TABLE VII — ORDER OF DISKS ACCORDING TO THEIR COEFFICIENTS
(BEST DISK FIRST)

Rate, gallons per minute per disk.	Total head.	DIAMETER OF DISKS.		
		2 inches.	3 inches.	6 inches.
		Radii.	Radii.	Radii.
	Feet.	Inches.	Inches.	Inches.
1.71	2	4 6 12 20	2 4 4 12 6 20 20	20 12 6 4
	4	4 20 6 12	4 2 4 6 12 20 20	20 12 6 4
	6	4 6 20 12	2 4 12 6 20 20	6 12 20 4
4.08	2	4 6 12 20	2 4 4 12 6 20 20	6 20 12 4
	4	4 6 12 20	2 4 4 6 12 20 20	6 12 20 4
	6	4 6 20 12	2 4 6 12 20 20	12 6 20 4
8.47	2	4 6 12 20	2 4 4 6 12 20 20	6 4 12 20
	4	4 6 12 20	2 4 4 6 12 20 20	6 12 20 4
	6	4 6 12 20	4 2 6 20 20 12	6 12 20 4

Efficiency evidently increases with the increasing concavity of the disks. Disks Nos. 12 and 16, with very flat surfaces, gave such poor results that they have not been plotted. The improvement with increase in curvature is most marked with the disks of small diameter, and with the 6-inch disks the 12-inch radius of curvature is the maximum, the 4-inch radius giving very poor results. This is brought out more clearly in Figure 12, where the coefficients at the 4-foot head are plotted against the actual depth of the disks of various diameters. An increase in concavity increases the efficiency of the disk by breaking the liquid up more completely and sending it higher into the air. The accompanying increase of disk surface over which the liquid must travel tends, however, to decrease the efficiency of distribution, probably by the greater friction involved. With small disks this is not serious, but as the surface is increased this factor limits the possible increase in concavity. Disk No. 15, with a diameter of 5 inches and a radius of curvature of 3 inches, represents an extreme condition in which the liquid did not splash at all, but eddied about in the deep cup and merely dripped over the edge.

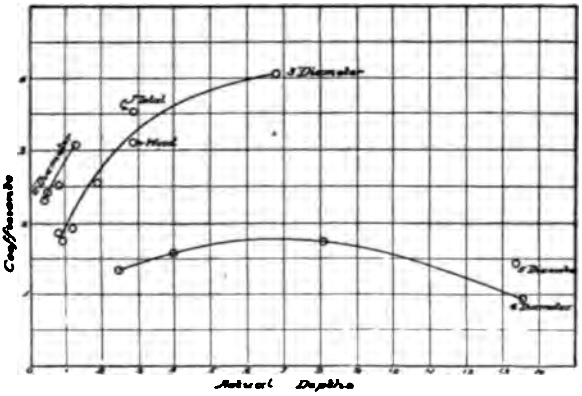


FIG. 12.—RELATION BETWEEN DEPTHS AND COEFFICIENTS FOR DISKS OF DIFFERENT DIAMETERS

Rate = 4.08 gallons per minute. Total head = 4 feet. Best head-on-sprinkler in each case

The only other point noted was the effect of the composition of the disks. Nos. 6, 7, and 15 were of metal, spun out of No. 18 sheet copper. All the others were of white pine, turned and carefully smoothed on the lathe, and varnished. No. 15, as noted above, was of very poor shape, but Nos. 6 and 7 gave the best results obtained in the whole series. No. 7 had a 2-inch radius of curvature, and should therefore have given better results than the others, which were of less concavity. No. 6, however, was of the same size and shape as No. 10 (of wood). Its coefficients were distinctly better under the most favorable heads. Thus at the 4.08-gallon rate, with a 6-foot total head and 2.5-foot head-on-sprinkler, No. 6 gave .49 against .42 for No. 10; with 4-foot head-on-sprinkler it gave .56 against .44.

In general, it appears from this portion of the investigation that the best results with gravity distribution can be obtained under the following conditions:

1. The discharge on each sprinkler should be in the neighborhood of 4 gallons per minute; this means, for a 2,000,000-gallon rate, 340 sprinklers per acre, with a distance between the sprinklers of about 11 feet.

2. The head between the distributing trough and the filter should be as great as possible; 2 feet is inadequate, 4 feet gives fair results, and 6 feet is better. Where exceptional conditions make still higher heads possible, the use of large, deep disks might prove of advantage.

3. The head on the sprinkler should be from 2 to 4 feet. The best subdivision of available total head can probably best be determined by experiments with the disks to be used in each individual case.

4. A simple concave disk of metal seems to promise the best efficiency.

5. The best diameter for the disks appears to be 3 inches. For low rates of discharge smaller disks are better, and for very high rates or very high heads larger ones may be more suitable.

6. Unless the disk be too large it is of advantage to increase its concavity as much as possible. Of 3-inch disks, that having a curvature corresponding to a radius of 2 inches proved most satisfactory. The radius of curvature might profitably be increased toward the limiting value of 1½ inches, which would make the disk a hemisphere. With larger disks larger radii of curvature are necessary.

Of all the disks studied, the best was No. 7, a metal cup, 3 inches in diameter, with a radius of curvature of 2 inches. With a total head of 4 feet and a head-on-sprinkler of 3 feet, it gave a coefficient of .40, the best obtained with that total head; and with a total head of 6 feet and a head-on-sprinkler of 4 feet, it gave the highest coefficient obtained for any gravity distributor, namely, .62.

A. DETERMINATION OF COEFFICIENTS FOR PRESSURE DISTRIBUTORS

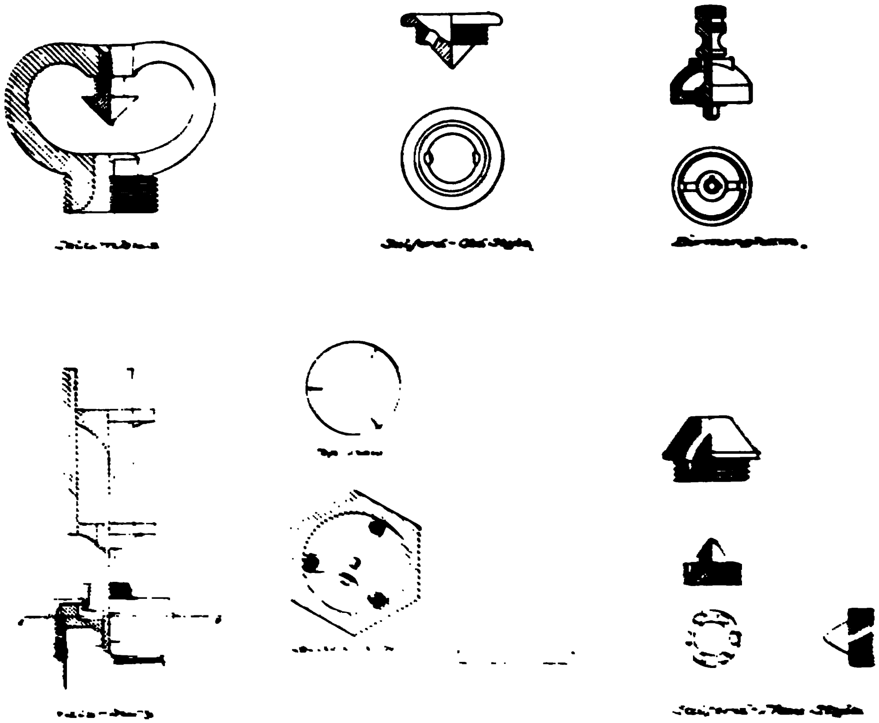
The system of spraying sewage upward from fixed sprinkler nozzles under pressure was developed more or less independently at various plants in England. At Salford it was worked out after the failure of various other methods, in which the sewage overflowed from troughs, or was spread by a thin layer of sand covering the filter proper. In the earlier experiments with fixed nozzles, a disk-like cap was placed a little above each in order to break the sewage into a fine spray. Then the attempt was made to break up the stream by the impact of two converging flows; and finally a nozzle was designed which [illegible] the sewage from a series of openings arranged spirally [illegible]. In Derbyshire, Ruwise describes as common the use [illegible] pipes with metal disks placed over the outlet to [illegible] like the earliest Salford type). At Birmingham [illegible] heads are used, in which the sewage passes up [illegible] and is broken up and thrown outward [illegible] of a metal plug raised a little above it.

[illegible] filter distribution were made [illegible] experiments of 1904–05 a [illegible] at Salford. The sewage [illegible] angle of 45° [illegible] [illegible] that a single opening with a cone above for distribution, supported at the sides as in the Columbus nozzle, proved unsatisfactory. The side supports broke the sheet badly, especially after the development upon them of a fungous growth. Furthermore, he points out that the "uniformity of distribution obtained by means of a single cone acting under a head of 5 feet was not satisfactory. Although the efficiency as marked by the area wetted was approximately 75 per cent., a certain outer zone invariably received sewage at a higher rate than the inner area. To lessen this defect, and to secure a greater percentage of wetted area and a more uniform distribution of the sewage, the idea occurred to the writer of placing a lower and secondary cone over the orifice, with the object of intercepting a portion of the sewage and distributing it over the inner fifth of the circular area within the range of the nozzle. The result was effected by boring a hole through the lower cone slightly less in diameter than the fixed orifice in the nozzle, the diameter of the opening in the cone being so proportioned to the diameter of the nozzle orifice that four-fifths of the rising stream passes through the lower cone to be diffused by the upper, and the remaining fifth is sheared off by the lower cone and sprinkled over the central area."

It is evidently desirable to have an accurate measure of the comparative performance of these sprinkler nozzles and of the still better designs which the future will probably develop. Mr. Gregory, in describing the Columbus experiments, was content to say that the nozzle used wetted 77 per cent. of the tributary area "in a perfectly satisfactory manner." Mr. Taylor noted, but did not measure, serious inequalities of distribution within the wetted area. We were therefore particularly glad to apply our method of measuring efficiency to the most promising of these pressure nozzles, and the results have proved significant. Through the kindness of Mr. G. C. Whipple, of New York, we have been furnished with two of the nozzles used at Salford and with the Birmingham type. To Mr. Gregory we owe the Columbus sprinkler, and Mr. Taylor has courteously given us drawings of the Waterbury design. The tests of these five types may best be discussed one by one, and reviewed in comparison with each other later.

The Salford nozzle (old style) is a brass nozzle in the form of a cup, with two openings in the sides at such an angle that the streams discharged upward from them meet in the cup itself. Its construction is shown in Figure 13.

This nozzle differed from all others tested in the fact that it did not discharge equally along different radii. It threw the liquid up in a fan-shaped spray, in quite a narrow plane, as indicated in Figure 14. Our ordinary method of rating efficiency, which assumes symmetrical distribution about the centre, was of course inapplicable under such circumstances. Instead, therefore, of revolving the measuring tank about this sprinkler, we measured the discharge at six different station-



[illegible]

[illegible] covering [illegible] The average [illegible] above for [illegible] each [illegible] tions [illegible] also it [illegible] deter- [illegible] The product of the crude coefficient and the radial coefficient measures the evenness of distribution within the wetted area.

When this sprinkler nozzle was tested under a head of 6.4 feet, another anomaly appeared in connection with the determination of the corrected coefficient. The area wetted was larger than the square which would be tributary to each sprinkler at a 2,000,000-gallon rate.

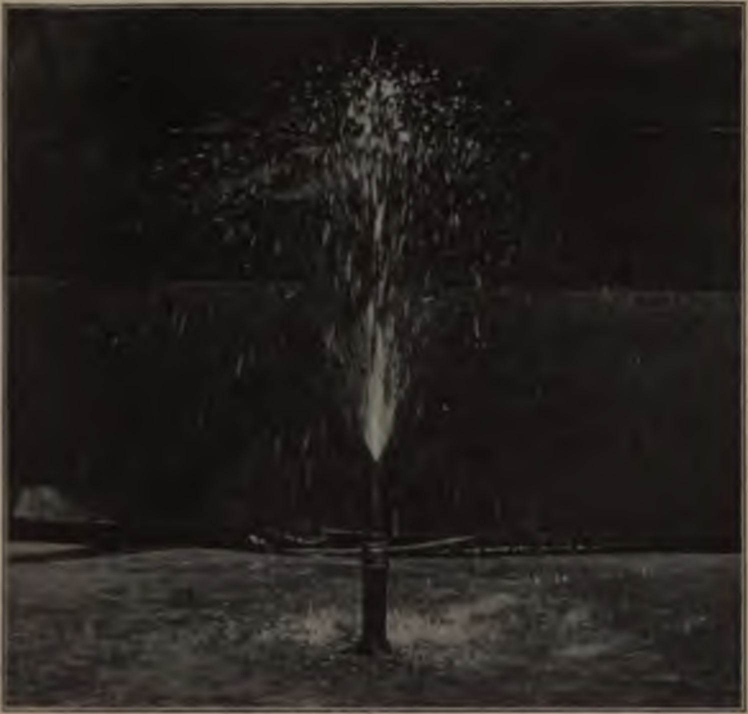


FIG. 14.—VIEW OF SALFORD OLD STYLE NOZZLE IN OPERATION

This means, of course, that at this head and rate the circles would overlap. The following method of calculation was applied in this case and in others of the same kind.

The effect of overlapping circles of spray is exactly the same as it would be if each portion of the spray passing the boundary of the tributary square were perfectly reflected at the side of that square and returned to a corresponding point within. It is necessary, therefore, to calculate how much of the discharge into the outer rings would have been thus reflected, or, in other words, what proportion of each of the overlapping rings falls without the square. Given the dimensions of the square and of each ring, this is a simple problem in trigonometry, the solution of which gives,

$$\frac{P}{100} = \frac{\cos^{-1}\dfrac{S}{D}}{45^\circ},$$

in which S is the side of the square and P the percentage of the total discharge into any overlapping ring of diameter D, which would be reflected to an inner ring. Having subtracted from all the rings the amounts which would be reflected, it is next necessary to distribute these amounts among the inner rings where they properly belong. The mathematical solution of this problem gave a result too cumbrous to use. A graphical representation of the conditions drawn on plotting paper, however, indicated readily and with sufficient accuracy the amounts of the reflected discharge which would fall into each of the inner rings affected, and the reflected water was then redistributed. These new values were then recalculated like the others and a coefficient obtained, which referred, not to a circle, but to the area common to the maximum circle and the intersecting square. The relation between this area and that of the square furnished the required factor for the calculation of the corrected coefficient from the crude.

The results of the tests on the Salford old style nozzle are shown in Table [illegible]. The total head in this and succeeding tables is the difference in level between the surface of the liquid in the supply box and the top of the measuring tank. The head-on-sprinkler is the difference in level between the surface of the liquid and the nozzle itself. In general, the [illegible] placed as close as possible to the top of the tank.

[illegible] brought out in the [illegible] feet was [illegible] apparently due to the [illegible] this nozzle [illegible], which at [illegible]

TABLE VIII—COEFFICIENTS FOR SALFORD OLD STYLE PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Coefficients.			
			Crude.	Radial.	Product.	Corrected.
Feet.	Feet.					
2.0	1.9	2.6	.65	.56	.36	.03
4.1	3.9	3.8	.73	.53	.38	.16
6.4	6.2	2.9	.76	.58	.44	.41

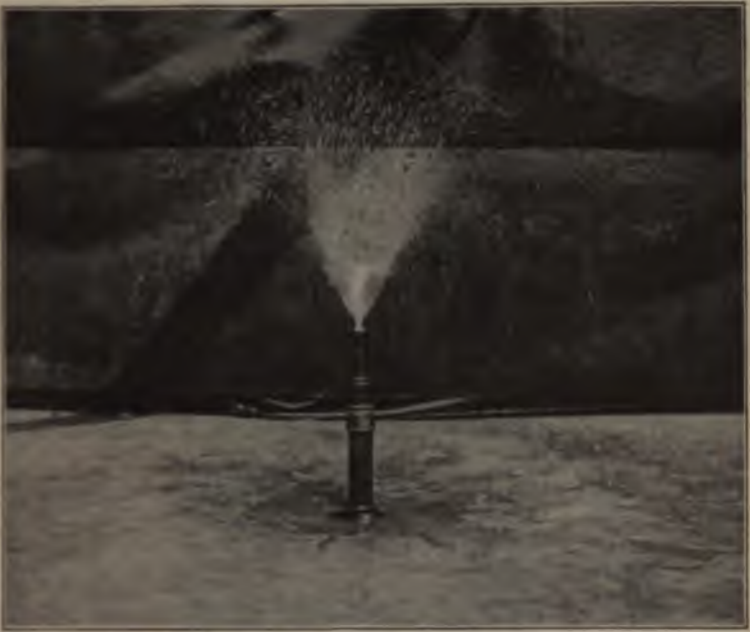


FIG. 15.—VIEW OF SALFORD NEW STYLE NOZZLE IN OPERATION

It is evident from the column of crude coefficients that this nozzle secures a fairly even distribution within the wetted sector, improving with the head to a very high value. There is an area of excessive discharge near the outer limit of the wetted sector, but the excess is not great. The inequality of distribution along different radii is much more serious. Nearly half the liquid is discharged in excess on one of the six 30° sectors, and this weakness causes the products and corrected coefficients to be poor.

The Salford new style sprinkler tested is a double cone, the outer cone being open at the top. The liquid enters the space between the cones through six holes of $\frac{5}{32}$ inch diameter, inclined at an angle to the major axis, so that a spiral motion is produced within the inner cone. This sprinkler is shown in Figure 13, and its general method of operation is indicated by the photograph reproduced in Figure 15.

With this, as with the other pressure nozzles, distribution along different radii was approximately equal, and tests were made in the manner described in Section II by revolving the measuring tank about the distributor. Duplicate determinations were made at each of the three heads tested, and the results are shown in Table IX. As in the case of the old Salford nozzle, at high heads a wetted area was obtained extending beyond the sides of the calculated tributary square, and the factor was therefore corrected by the method described above (page 359). The crude coefficients refer in all cases to the actual wetted circles.

TABLE IX—COEFFICIENTS FOR SALFORD NEW STYLE PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	2.2	0.7	.37	.22
2.2	2.2	1.2	.44	.16
4.5	3.8	1.6	.68	.39
4.5	3.8	1.7	.70	.38
9.8	6.1	2.0	.78	.67
9.4	6.1	2.1	.77	.65

The results of these tests indicate that the new Salford sprinkler gives very good results at the higher heads. The tests themselves show an excessive discharge on the outer part of the wetted area, but the excess is small, giving crude coefficients of .6 and .7 at 3.8-foot and 6.1-foot heads. At the 3.8-foot head, however, the wetted area (a circle of 3 feet radius) is small in proportion to the rate. The corrected coefficient is therefore poor, while that obtained at the 6.1-foot head, with only slightly higher rate and a circle of 4 feet, remains in the neighborhood of .7.

The Birmingham nozzle, shown also in Figure 13, discharges through a [illegible]-inch opening. Through this opening passes a [illegible]-inch shank, the enlarged upper portion of which breaks up the ascending ring of liquid and sends it out in a fine spray. The working of the nozzle is shown in Figure [illegible], and its results are indicated in Table X. In this case the discharge through the opening was so small and the distribution so good that a circle larger than the proper tributary square was wetted in every test except those made at the 2.2-foot head. The results are therefore corrected, as in the cases above.

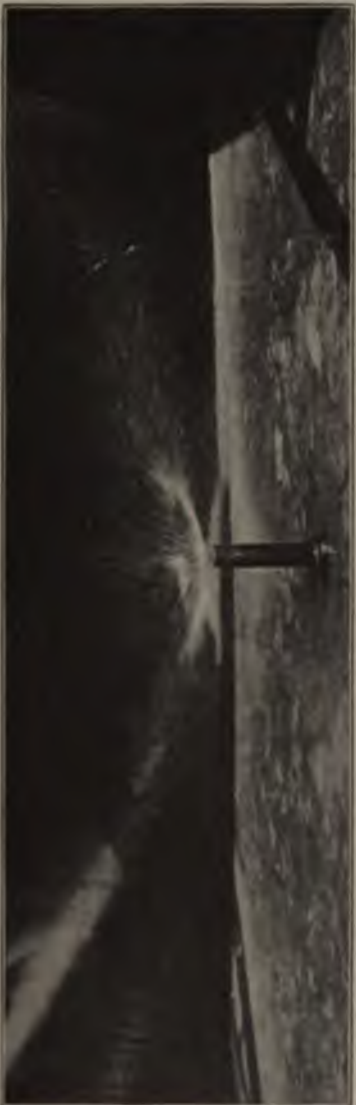


FIG. 16.—VIEW OF BIRMINGHAM NOZZLE IN OPERATION

TABLE X — COEFFICIENTS FOR BIRMINGHAM PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	2.0	0.9	.58	.44
2.2	2.0	1.0	.62	.38
4.3	4.1	1.4	.80	.80
4.3	4.1	1.5	.76	.72
6.4	5.8	1.8	.84	.69
6.4	5.8	2.0	.78	.66

These figures are of the greatest interest as showing what results may be obtained with a nozzle of small bore so arranged as to break up the stream quickly and completely. With a low rate of discharge, due, of course, to the obstructive construction of the orifice, a relatively large circle was covered (of 2.5 feet radius at the 2-foot head, 4 feet radius at the 4.1-foot head, and 5 feet radius at the 5.8-foot head); and within this circle the distribution was remarkably even. With this nozzle the 4-foot head proved better than the higher one, since at the 5.8-foot head a more definite ring of excessive discharge was formed. Under the best conditions this nozzle gave corrected coefficients of .7 to .8. It is clear that the Birmingham nozzle effects a far more perfect distribution than any other device we have examined.

The Columbus nozzle is designed on a plan exactly opposite to that of the Birmingham sprinkler, in so far as it aims to enlarge the orifice of discharge as much as possible. The Columbus design has been described above, and is also shown in Figure 13. Figure 17 illustrates its method of operation.

TABLE XI — COEFFICIENTS FOR COLUMBUS PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	[illegible]	[illegible]	[illegible]	.12
2.2	[illegible]	[illegible]	[illegible]	.14
4.3	[illegible]	[illegible]	[illegible]	.21
4.3	[illegible]	[illegible]	[illegible]	.22
6.4	[illegible]	[illegible]	[illegible]	.30
6.4	[illegible]	[illegible]	[illegible]	.35

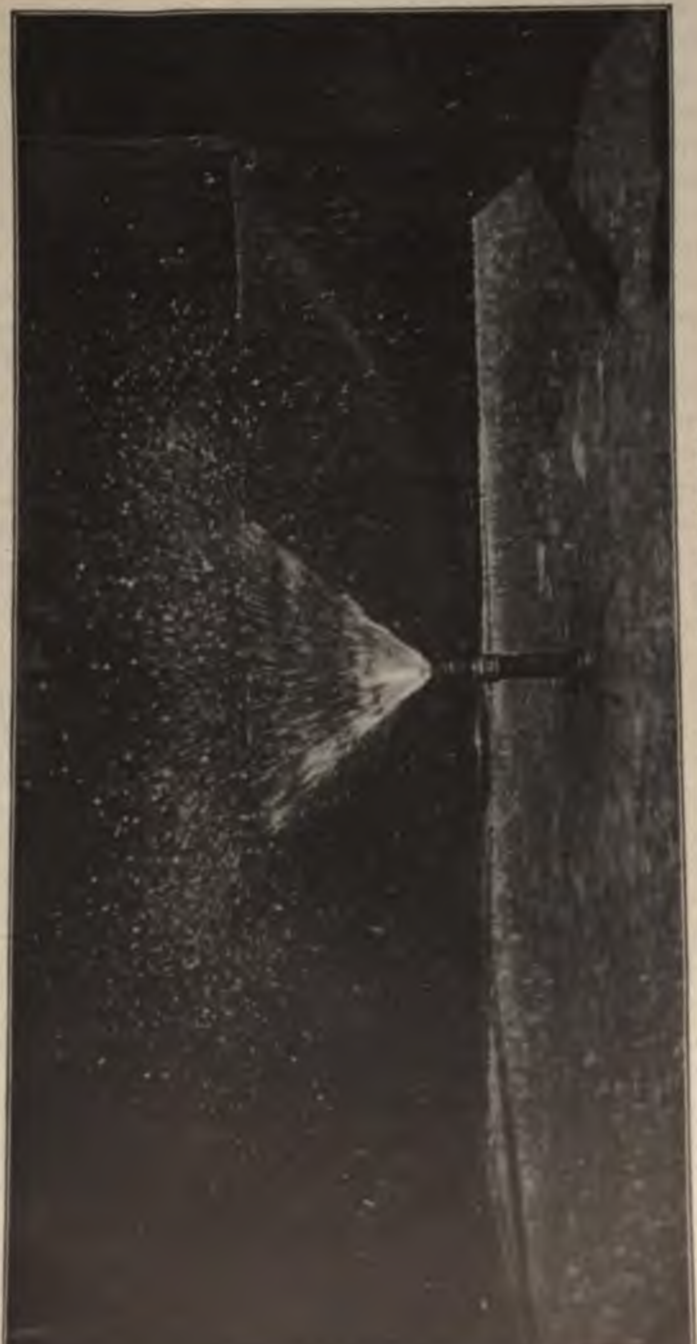


Fig. 17.— View of Columbus Nozzle in Operation

The Columbus sprinkler shows at all heads a fair distribution within the wetted area, its departure from the ideal condition being due to the formation of a zone of excessive discharge a little inside the periphery of the wetted area. Crude coefficients, however, are always about .6, and one notable thing about this nozzle is the fact that it gives fairly even distribution even at the 2-foot head. The wetted area is, however, small in proportion to the discharge, and therefore the corrected coefficients are poor. Thus at the 4.3-foot head, for example, the rate of discharge of the nozzle was 10.9 gallons per minute. This discharge, if the total rate on the filter be 2,000,000 gallons per acre, calls for 121 sprinklers per acre, which means a distance of 19 feet between sprinklers. The wetted circle at this head was only 6 feet in radius, so that at an ostensible 2,000,000-gallon rate half the filter area would be working at 4,000,000 gallons and the rest would be idle. It is no doubt for this reason that the Columbus engineers plan to operate at a 4,000,000-gallon rate for half the time, and to rest the whole filter the remainder of the time, spacing their nozzles 16.2 feet apart. This would of course give a distribution more nearly approaching our crude coefficients, though the results at best would be below .6.

The Waterbury nozzle used in these experiments was of the type described on a preceding page (356), in the citation from Mr. Taylor's paper. Its construction is indicated in Figure 13. Briefly the nozzle consists of two cones, one above the other, the lower one perforated at its centre. An annular discharge is in part deflected outward by the lower cone, while its inner portion passes through the lower cone and is deflected by the upper one. As shown in Figure 18, the result is to produce two concentric cones of spray and thus improve the distribution obtained with a nozzle of the Columbus type. In the sprinkler tested by us, the position of each cone in relation to the point at which the liquid leaves the pipe below could be varied by means of set screws, and a number of different settings of these cones were examined. The distance between the lower opening and the lower surface of the lower cone at its outer rim is designated by the letter *a*; the distance between the upper surface of the lower cone and the lower surface of the upper cone is designated by the letter *b*. Reference to Figure 13 will make the significance of these dimensions clear.

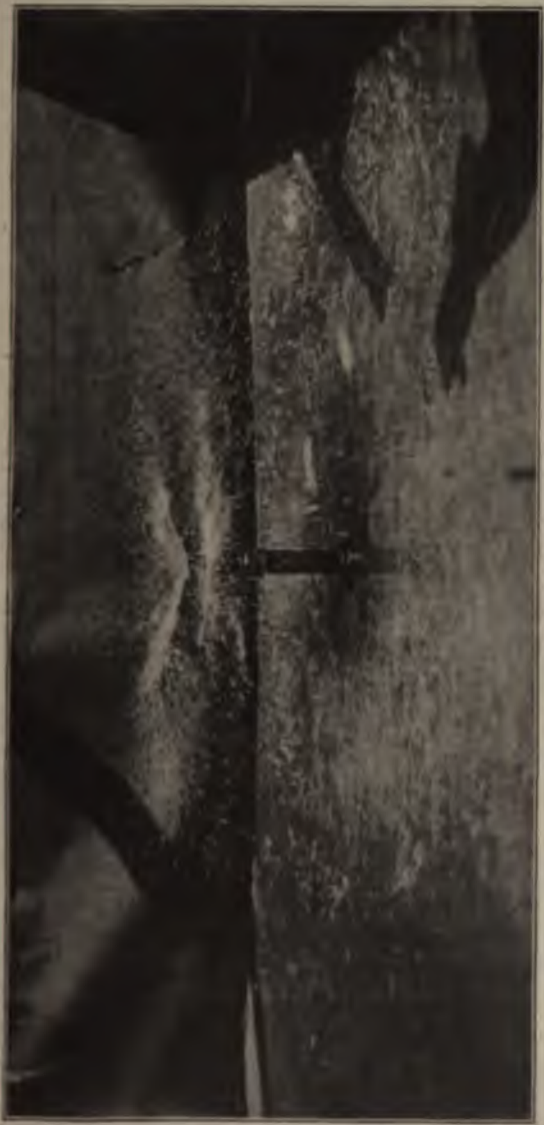


FIG. 18.—VIEW OF WATERBURY PERCONATE NOZZLE IN OPERATION

TABLE XII — COEFFICIENTS FOR WATERBURY PRESSURE DISTRIBUTORS

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	HEIGHT OF CONES.		Crude coefficient.	Corrected coefficient.
			a.	*b.*		
Feet.	Feet.		Inches.	Inches.		
2.2	2.2	5.4	1⅜	1¾	.46	.05
2.2	2.2	5.6	1⅜	1¾	.45	.05
4.3	4.3	7.6	¾	1¾	.53	.11
4.3	4.3	7.8	¾	1¾	.62	.13
4.3	4.3	7.5	1⅜	1⅛	.62	.13
4.3	4.3	7.7	1⅜	1⅛	.62	.14
4.3	4.3	7.6	1⅜	1¾	.62	.14
4.3	4.3	7.7	1⅜	1¾	.68	.14
4.3	4.3	7.8	1⅜	1¾	.66	.13
6.4	6.3	6.8	¾	1¾	.68	.21
6.4	6.3	10.2	¾	1¾	.72	.21
6.4	6.2	8.6	1⅜	1⅛	.62	.15
6.4	6.4	9.6	1⅜	1⅝	.69	.22
6.4	6.4	10.4	1⅜	1⅝	.73	.22
6.4	6.2	9.3	1⅜	1¾	.77	.21

The results of the tests on the Waterbury sprinkler are indicated in Table XII. It will be noticed that the rates varied somewhat under the same conditions. This was no doubt due to the tendency of this sprinkler to clog. Our tests were all made with water, but the tanks through which it was pumped were not perfectly clean and at times contributed their quota of suspended solids (old sewage sludge). These inequalities did not, however, seriously affect the coefficients, which are fairly uniform. It appears from this table that the relative position of the cones does not greatly modify the efficiency of distribution, although there is a slight but distinct improvement in coefficients with an increase in the value of *b*. That is, an increase in the distance between the upper and lower cone improves distribution by throwing the outer cone of liquid further out and separating it more distinctly from the inner one.

In all cases, however, there is more or less fusion of the two cones of spray, and our tests showed a single zone of excessive discharge, not near the periphery of the wetted area, as with the Columbus nozzle, but about a third or a half of the way out from the centre of the wetted circle. The crude coefficients at 4.3-foot and 6.4-foot heads were a little higher than those obtained with the Columbus nozzle, averaging a little over .6 for the lower and about .7 for the higher head. The wetted area with this nozzle is, however, small for its high rate of discharge. The largest circles wetted were 11 feet in diameter, and this was at rates of about 10 gallons per minute, corresponding to distances of 18 feet between sprinklers. The corrected coefficients are therefore low, the best of them being barely over .2.

Mr. Taylor has worked out certain modifications of his sprinkler which have not been examined in the present investigation, but which well deserve a careful study. Two of these are described in the paper previously cited (*Engineering Record*, **55**, 10) and more fully in a somewhat later one (*Engineering News*, **57**, 238). One consists of a six-winged revolving cone supported directly over a single orifice, through which the sewage rises. The six blades, shaped like air blowers, are rotated by the force of the liquid striking them, and their curvature gives the drops of sewage, leaving them a widely varying angle of elevation. A still more interesting nozzle has a cone similar to that tested in our experiments, but with a vertical cut in each quadrant of the cone. The upper surface of the conical piece has almost the shape of a four-leaf clover, though not cut in so deeply, and the sewage is discharged from the outer rounded corners at a more oblique angle than from the incised areas between. It is hoped that by the proper construction of a cone of this type "the sewage film when leaving shall have such varying angles of elevation that it shall, upon diffusion, throw the proper proportion of drops the distance required to cover the side of the square, while midway between these points, on the diagonal lines, the drops will, by reason of their greater angle of elevation, be thrown with the tendency to fill the corners of the square."

VI. THE EFFICIENCY OF PRESSURE DISTRIBUTORS WITH VARYING HEADS

With a sprinkler which, like many pressure nozzles, discharges in a conical sheet and forms an excessive discharge on a peripheral zone, it would seem to be of advantage to vary the head-on-sprinkler in such a way as to cause the zone of excessive discharge to travel in and out over the wetted area. This may easily be done by the interposition of siphon tanks in the supply system, and such is the practice at many of the English plants, notably in Derbyshire (Barwise, "Purification of Sewage," London, 1904). The Board of Advisory Engineers to the [illegible] arrangement [illegible]

[illegible] sion [illegible]

[illegible] ons [illegible]

[illegible] The [illegible] defi- [illegible] comparison in

TABLE XIII—COEFFICIENTS FOR COLUMBUS DISTRIBUTOR WITH VARYING HEAD

Maximum head.	Minimum head.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.		
4.3	4.3	.63	.21
4.3	4.3	.65	.22
4.0	2.0	.45	.30
4.0	2.5	.50	.33
4.0	3.0	.56	.37
4.0	3.0	.56	.37
4.0	3.2	.53	.41
4.0	3.5	.53	.41
4.0	3.5	.55	.43
3.7	3.5	.49	.32
3.7	3.5	.48	.38

It was expected, *a priori*, that a varying head would give more even distribution within the wetted area; and to the eye the waxing and waning cone of spray looks well-nigh perfect. Nothing could better illustrate the importance of the rigorous method of measurement adopted in these experiments. The crude coefficients in Table XIII are distinctly poorer with varying than with constant heads. An inspection of the original measurements shows the presence of a well-marked zone of excessive discharge just as in the case of the constant head, only not so far out from the centre of the wetted area. A large excess of the liquid was found in the compartments 2 and 2½ feet out from the nozzle. The smaller radial distance of this maximum zone accounts for its greater effect in reducing the coefficient.

On the other hand, the corrected coefficients were much improved by the intermittent operation. The wetted area was as great as in the tests at a constant head of 4 feet and the discharge was much less. The average rate was as low as 4 gallons per minute per sprinkler. Therefore, for a total rate of 2,000,000 gallons per acre the nozzles could be placed much closer than at a 4-foot constant head (11 feet instead of 19), and the wetted area made to approximate more nearly to the tributary squares. Thus the corrected coefficients for a head varying from 4 feet down range from .3 to .4 against a little over .2 for the constant head of 4.3 feet.

With regard to the best construction for a siphon tank, Table XIII brings out several suggestive points. Taking the maximum heads of

4 feet, it is app hat the evenness of distribution within the wetted area is better when the tank is not too long in emptying, since the crude coefficients are better with a minimum head of 3 feet and over than with lesser ones. As the minimum head is increased, the corrected coefficient rises still more rapidly, increasing progressively from .30 to .43. This is because the wetted area at 3.2 feet and 3.5 feet minimum heads was somewhat larger than with a lower minimum, while the evenness of distribution was as good as at a 3-foot minimum head. Evidently the best siphon tank is one with a short range of level which will discharge a small volume of sewage at frequent intervals. In our tests the best arrangement was such that the tank filled and emptied in about one minute, the change of head being from 4 feet to 3.5 feet. The decreased maximum head in the last two lines of the table shows an injurious effect on both crude and corrected rates.

The siphon tank used in these experiments was a simple box of square section, but Mr. Taylor (*Engineering Record*, 55, 10) has suggested a design which promises better results. He points out that on theoretical grounds a nozzle acting under a straight-line variation of head from maximum to minimum, such as that produced by the discharge of an ordinary tank under siphon action, could not lead to perfect results. To produce ideal distribution the head upon the nozzle should vary less rapidly near the maximum point than near the minimum. He found that the rate of the desirable variation was represented by a parabolic line.

VII. COMPARATIVE EFFICIENCY OF DISTRIBUTORS OF VARIOUS TYPES

The optimum conditions for distributors of various types have been somewhat fully discussed, but a brief comparative summary of their performance may be of interest in closing. We have therefore summarized the results under optimum conditions (4-foot total head for Birmingham, 6-foot for the others) in Table XIV.

TABLE XIV—COMPARATIVE EFFICIENCY OF DISTRIBUTORS OF VARIOUS TYPES

Type.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.	Sprinklers per acre to discharge 2,000,000 gallons per day.
Best gravity distributor	4.08	.76	.62	341
Old Salford	2.9	.44	.41	483
New Salford	2.1	.78	.67	667
Birmingham	2.0	.80	.80	700
Columbus	14.8	.61	.30	94
Waterbury	10.4	.73	.22	134

The American pressure nozzles, judged on the basis of these measurements, show a low efficiency in distribution. They cover the wetted area fairly well under the best conditions, but their discharge is so excessive that at a total rate of 2,000,000 gallons per acre they leave large waste areas between, and their corrected coefficients are correspondingly low. It must, of course, be remembered that at a rate of 4,000,000 gallons per acre, for which the Columbus nozzle at least is designed, the corrected coefficients would be much higher. Furthermore, the performance of these nozzles may be further improved by the use of varying head, which increases a coefficient of .2 (for 4-foot total head) to .4 (for a head varying between 3.5 feet and 4 feet). This question of varying heads well deserves further study, especially in the light of Mr. Taylor's plan for parabolic variations. The Columbus nozzle offers great advantages in the simplicity of its construction and in its large orifice if its excessive discharge can be overcome by the use of siphon tanks.

The best of the gravity distributors (a 3-inch metal disk with a 2-inch radius of curvature) has given much better results than we had hoped for it. Without the complication of siphon tanks and varying head, it shows a corrected coefficient of .62, double that obtained for the Waterbury and Columbus nozzles under the same conditions. With a 4-foot total head its coefficient is .40, while the Columbus nozzle gives .22 with a similar constant head, and the best Columbus nozzle value with a varying head is only .43. The smallest opening for clogging in the gravity system is the discharge pipe, ¾ inch in diameter, while the diameter of the Columbus nozzle is $\frac{9}{16}$ inch. Furthermore, the accessibility of the whole distribution system makes its maintenance in good condition easy.

The new Salford and Birmingham pressure nozzles produce the most efficient distribution of any of the devices tested. At a 6-foot total head the Birmingham coefficient is .69, and at a 4-foot total head it is still better (.80), the distribution being almost perfect. These good results are, however, gained by the use of nozzles which are extremely liable to clogging. The openings of the new Salford nozzle are only $\frac{5}{32}$ inch in diameter, and the cone into which they discharge is admirably adapted to collect solid materials. The opening in the Birmingham nozzle is a ring only $\frac{5}{64}$ inch in diameter. Its removable plug indicates that even with the carefully screened and septicized sewage of Birmingham it requires frequent attention; and it is difficult to see how any such device could be economically used under American conditions, even with septic sewage. On the other hand, crude sewage can be sprayed by the Columbus nozzle or the gravity distributor without difficulty from clogging.

[Reprinted from TECHNOLOGY QUARTERLY, Vol. XIX, No. 4, December, 1906]

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND
SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS
INSTITUTE OF TECHNOLOGY

THE STERILIZATION OF SEWAGE-FILTER EFFLUENTS

BY EARLE B. PHELPS AND WILLIAM T. CARPENTER

THE DESIRABILITY OF STERILIZATION

THE primary purpose of sewage purification is the protection of the purity of the streams. The Lawrence experiments first showed that, by means of sand filters, sewage could be purified to an extent which is for all practical purposes complete. This means that practically all the organic matter and the living bacteria of the sewage are either removed or converted into harmless mineral constituents. Such a degree of purification is possible, but it involves the use of such large areas of suitable sandy land that, except under the most favorable circumstances, its cost to a city of moderate size is practically prohibitive. Consequently the tendency for the past decade has been toward more rapid processes of purification; that is, processes requiring smaller areas of land for the treatment of given volumes of sewage. The results of experiments along this line, carried on in many parts of the world, are now well known. We have seen the successive development of the septic tank, the contact filter, and the trickling filter, each of which has resulted in an increase in the possible rate of treatment, until the original maximum rate of fifty or sixty thousand gallons per acre per day has been multiplied fifty fold or more. This great saving in filter area has not been obtained without some sacrifice. With the progressive increase in the rate of treatment there has come a more or less progressive deterioration in the quality of the effluent, so that the effluent of a modern trickling filter, so far as appearance goes, and indeed often in its chemical analysis, seems to be little better than the crude analyses, but there are certain aspects of the present subject which are, primarily, sanitary. The relation of sewage disposal to water filtration has already been commented upon. In the discussion of the economic phase of this relation it was assumed that satisfactory purification of the water would be obtained at whatever cost. Where polluted waters are being taken directly into the city mains the question is naturally a serious sanitary one, but again it must be asserted that the responsibility rests upon that community using the water. The most efficient purification of the sewage before discharge will never make a water safe which drains a populated country. The sewage can and should be rendered non-putrescible, but it will still be germ-laden. The removal of these residual germs, together with those others which by scores of devious and hidden paths have found their way into the stream, must depend upon the water works authorities. The case is aptly put by that dictum ascribed to Mr. Hering: "Nothing to be discharged into a stream without purification; nothing to be taken from a stream without purification." The greatest good to the greatest number finds its solution in this system of dual responsibility.

Sewage disposal has, therefore, curiously enough come to be less and less a matter of sanitation. As the practice has gradually developed from the slow sand filter toward rapid, coarse-grained filters, it has become more obvious that the removal of bacteria is not one of the functions of a sewage filter. There is, as a rule, a removal of a portion of these organisms. Whether or not there is a satisfactory elimination of the dangerous germs of disease is a point upon which there is great diversity of opinion and very little exact knowledge.

It was seriously feared at one time that pathogenic germs might multiply in the septic tank. Woodhead made physiological tests of crude sewage and septic tank effluent, and concluded that there were no organisms in the latter capable of setting up morbid changes in animals after inoculation. Rideal states that "satisfactory evidence in most of the systems is now available, from which I think we are justified in concluding that, even if towns on a river like the Thames adopted bacterial schemes, the pathogenicity of the London water supply would not be adversely affected." (Great Britain, 1902, A, Quest. 4148.)

On the other hand, Houston, acting for the Royal Sewage Commission, made a careful bacteriological study of the whole problem. He concludes that:

The effluents from septic tanks, intermittent contact beds, continuous filtration beds, etc., contain an enormous number of bacteria. In some cases the percentage reduction of microbes in effluent as compared with raw sewage is striking; but as an effluent must be judged by the actual state it is in, and as the number of microörganisms still remaining is almost always very large, percentage purification would seem to be of minor importance. In not a few cases the bacteria are practically as numerous in the effluent as in the raw sewage.

The different kinds of bacteria and their relative abundance appear to be very much the same in the effluents as in the crude sewage. Thus, as regards undesirable bacteria, the effluents frequently contain nearly as many *B. coli*, proteus-like germs, spores of *B. enteritidis sporogenes* and streptococci, as crude sewage. In no case, seemingly, has the reduction of these objectionable bacteria been so marked as to be very material from the point of view of the epidemiologist. No definite proof has been furnished that the effluents from bacteria beds are conspicuously more safe in this sense in their possible relation to disease than is crude sewage. Indeed, all the available evidence tends to show that they must be regarded as nearly if not quite as dangerous to health as raw sewage. In this connection we would again take note of the streptococcus test. If it be true that streptococci are more delicate germs than the typhoid bacillus, their presence in any number in the effluent would seem to indicate the possibility or probability of the enteric fever bacillus also surviving under similar conditions, and, in general, would lead us to infer that the biological processes at work were not strongly inimical, if hostile at all, to the vitality of germs of pathogenic sort. (Great Britain, 1902, B, p. 26.)

At the Sewage Experiment Station of the Massachusetts Institute of Technology, bacteriological examination of crude sewage and of the effluents of four septic tanks and fifteen filters were made during the summer season. The following average results were reported by Winslow (1904):

Sample.	Number of Examinations.	BACTERIA PER CUBIC CENTIMETER.					
		Lactose gelatin at 20° C.			Lactose agar at 37° C.		Anaërobic agar.
		Liquefiers.	Acid formers.	Total.	Acid formers.	Total.	
Sewage	56	365,000	1,670,000	5,430,000	1,670,000	3,700,000	2,440,000
Septic effluent	56	162,000	405,000	1,750,000	650,000	1,040,000	930,000
Contact filters	140	60,000	270,000	1,060,000	290,000	570,000	440,000
Trickling filters . . .	18	134,000	114,000	451,000	284,000	1,170,000	200,000
Sand filters	15	500	1,300	9,100	11,400	43,000	1,200

There were four septic tanks running at storage periods of from twelve to forty hours, nine contact filters differing in material, depth, and rate, three trickling filters, and three sand filters, each set running with crude and two kinds of septic sewage.

The septic tank and two trickling filters now in operation at this station gave the following bacterial results, the figures being averages of the results of almost daily examination during the past summer.

	Bacteria per c.c. Lactose agar at 37°.	B. coli. Positive * tests in $\frac{1}{100000}$ c.c.
Sewage	1,300,000	65 per cent.
Trickling filter receiving sewage	750,000	35 per cent.
Septic effluent	1,650,000	66 per cent.
Trickling filter receiving septic effluent	750,000	35 per cent.

* The bile broth presumptive test, recommended by Jackson (1906), was employed.

About one-half the total organisms were removed by filtration, and the reduction of *B. coli* was practically in the same proportion. Such results as these would seem to justify fully the statement quoted from Houston.

We are still ignorant of the fate of the dangerous pathogenic organisms, so far as any direct experimental knowledge goes. In the absence of such knowledge it is only reasonable and safe to assume that such organisms do, in part, at least, pass through the filter.

We must therefore conclude that sewage purification by modern processes can be made to produce effluents which are reasonably clear and stable, but which are still germ-laden and, potentially, infectious; that the discharge of such effluents into streams or tidal waters will not bring about physical nuisance or economic damage; and that, so far as the use of water for domestic and industrial purposes is concerned, such [illegible].

At the present time, however, we are confronted with a consideration which [illegible] of sewage purification [illegible] sewage pollution and sewage [illegible] oyster and other [illegible] sewage. Both [illegible] magnitude of [illegible] shellfish is [illegible] is due to the discharge of untreated sewage into the rivers and tidal waters. In Great Britain it is more commonly the result of the discharge of partially purified effluents which are quite stable, as we have described them, but germ-laden. In many places the matter is being studied or agitated. In Great Britain the Royal Sewage Commission has issued a voluminous and valuable report upon the pollution of shellfish (Great Britain, 1904). In our own country the Massachusetts State Board of Health has had the question under investigation for several years, and has just issued a valuable report bearing upon the subject (Massachusetts, 1906); New York State has a Harbor Pollution Commission which for two years has studied conditions in New York Harbor; New Jersey is alive to the danger which threatens one of her great industries; and Baltimore is taking active steps to improve the sanitary conditions of upper Chesapeake Bay. The difficulties of the situation are obvious. A polluted river water may be rendered potable through filtration, but purification of shellfish seems to be out of the question. It follows, then, that the bacteria of sewage must not be discharged upon shellfish beds. The kind of purification which we have discussed will no longer serve, for sanitary considerations are here paramount. A higher standard of purity — a bacterial purity as well as an organic stability — must be demanded in such cases, or else the taking of shellfish must be prohibited. When the community is large and the shellfish industry small this latter alternative will probably prove the more satisfactory. Where small communities are polluting large and important beds, thorough purification by sand filters is not an unreasonable requirement. Unfortunately, the greatest shellfish areas of the country are so situated that they are subject directly or indirectly to possible pollution from concentrated populations.

In a carefully prepared paper on this subject by Mr. G. W. Fuller (1905) it is stated that the annual crop of oysters gathered along the Atlantic and Gulf coasts in 1902 amounted to over twenty-five million bushels, valued at over thirteen million dollars, and that the crop of clams was over two million bushels, valued at two million dollars. Over one-half of this total product came from the three states of New Jersey, Maryland, and Virginia, and were, in the main, grown in the waters of the Delaware and Chesapeake Bays, into which the sewage of Philadelphia, Wilmington, Baltimore, Washington, and other cities is discharged. At present, owing to the tremendous dilution of the polluting matters in these bays, the danger of pollution is in most cases remote, but it is significant, ever present, and ever increasing. The great value of the industry and the even slight danger to which it is now exposed has called for action on the part of those most interested. In Baltimore a system of sewerage and sewage disposal is being planned by which it is intended to remedy the present serious pollution of the Patapsco. In calling upon a commission of experts for advice, the Sewerage Commission of Baltimore distinctly specified "that the effluent proposed to be discharged into Chesapeake Bay or its tributaries in the system to be recommended by the engineers shall be of the highest degree of purity." By a coöperative arrangement between the states of New Jersey and Pennsylvania the condition of the Delaware River is being investigated, and measures will be considered by which the present serious pollution of that river shall be remedied.

It seems that in such cases the value of the industry, together with the difficulty of protecting the beds in any other way, will ultimately force upon the authorities one of two alternatives: complete purification by filtration through sand, or rapid and partial purification by means of contact beds or trickling filters, followed by some kind of sterilization.

The former is practically what has been recommended for the city of Baltimore, although it is there proposed to make use of sand filtration as a secondary process, following treatment on trickling filters. In this way the efficiency of the sand filtration is obtained at a considerable saving in filtration area. The Board of Advisory Engineers has estimated the cost of works for the complete treatment of seventy-five million gallons of sewage per day at $3,283,250, of which sum $1,042,750, or over 31 per cent., is for the supplementary treatment on sand filters. The annual cost of operation is estimated at $115,500, of which $55,000, or 48 per cent., is for the supplementary treatment (Baltimore, 1906). This gives some idea of the price which it is necessary to pay for effluents of bacterial purity over and above the cost of rendering the sewage stable and non-putrefactive. In regard to sterilization by chemicals, the engineers report that "to remove all bacteria remaining in the settled effluent from the sprinkling filters by disinfectants, such as hypochlorite of lime or of sodium or sulphate of copper, would be prohibitively expensive, and this opinion is based upon the best knowledge of the subject now available. The fact is, this alternative of chemical sterilization has not yet been reduced to its lowest terms. We have yet to learn how effective it may be made and at what cost, and what after effects, objectionable or otherwise, are likely to follow its employment.

A somewhat careful study of the question has forced the authors to the belief that there is much of value in this process, and that under certain circumstances and conditions which are common in this country, particularly where the oyster question is involved, it may be found to be the best possible solution of the whole problem.

In connection with an experimental study of certain kinds of chemical sterilization, the results of which are here presented, the literature of the subject has been thoroughly reviewed, and it is thought that a summary of our available information might prove of value. In connection with the experimental data which have been compiled, the all-important question of cost has been gone into in some detail, particularly in the case of those processes which in other respects appear to be feasible.

THE EFFICIENCY AND COST OF STERILIZATION

In Great Britain the somewhat indefinite allusions of the Royal Sewage Commission to the question of sterilization as a finishing process in sewage treatment have aroused a storm of discussion and resulted, at least, in clearing away many misconceptions. Sterilization processes of many kinds have been investigated, and the subject has been freely discussed. For the following classification of sterilizing agents and for many of the facts here cited the writers are indebted to Rideal (1905), whose careful paper on the subject discusses its possibilities in a thoroughly impartial manner. Other authorities are cited so far as possible. Except when otherwise stated, costs are based upon present Boston prices.

The various methods proposed for the sterilization of effluents will be taken up in the following order.

1. Heat.
2. Lime.
3. Acids.
4. Ozone.
5. Chlorine and its compounds.
    - (*a*) Chlorine gas.
    - (*b*) Oxychlorides.
    - (*c*) Chloride of lime; hypochlorites.

6. Copper and its compounds.
7. Miscellaneous.
    (*a*) Permanganate.
    (*b*) "Amines."

1. HEAT. — The use of heat has been suggested for the sterilization of sewage and effluents. In his testimony before the Royal Commission, Klein (Great Britain, 1902, A, Quest. 9674) referred to a patented apparatus which he considers quite feasible, and by the use of which enough ammonia was to be recovered nearly to pay for the fuel required. There is no record that this device has ever been used on a large scale, and its claims are almost too fanciful. A rough calculation of the anthracite coal necessary to raise sewage to the boiling point from the average temperature of 60° F. gives 40 tons per million gallons, which will cost say $4 per ton, or $160. The total amount of free ammonia in a million gallons of Boston sewage is about 100 pounds, which, if concentrated to the commercial strength of 28 per cent., would bring 40 cents per pound, or $40. These are the most favorable figures possible, and in reality the revenue would be a much smaller proportion of the cost. Sterilizing by heat, therefore, will be a very expensive process and may safely be disregarded.

2. LIME. — Caustic lime acts as a weak germicide. The considerable removal of bacteria noted when lime is used as a precipitant for sewage is undoubtedly due to the action of the precipitate itself in dragging down with it the bacteria which it has entangled. Such an action is common in all precipitation, and even the sedimentation of sewage is always accompanied by a great reduction in the numbers of bacteria. For use with effluents, therefore, lime alone would not seem to be a valuable germicide. Rideal states that sixty to seventy grains [illegible] are sufficient for sterilization. Thresh believes that lime would [illegible] a satisfactory sterilization of effluents, but has not tried it (Great Britain, 1902, A, Quest. [illegible]).

3. [illegible] acids than [illegible] cholera germs. [illegible] states that [illegible] in fifteen [illegible] that Ivanoff [illegible] cholera germs [illegible] found [illegible] as a result

obtained also by Rideal himself. To furnish one million gallons of sewage with .08 per cent. sulphuric acid would require 6,640 pounds of acid, at an approximate cost of $332. Smaller amounts of acid might be used, since it would not be necessary to kill typhoid germs in so short a time as fifteen minutes; but, on the other hand, there is in most sewage a considerable amount of free alkali requiring neutralization before any effect of the acid would be obtained. On the whole, this process would seem to be an impractical one except in cases of emergency. It is interesting to note that the sewage of Worcester, Massachusetts, contains normally an average of .01 per cent. free sulphuric acid, or half enough to kill cholera germs in twenty-four hours.

4. OZONE. — Ozone has been used with more or less success in various parts of Germany, particularly at Weisbaden, for the sterilization of drinking water. Although the process has been most favorably spoken of by those in immediate care of the investigations, it has not generally been regarded as a success, and its use at Weisbaden has been discontinued. There can be no doubt as to the possibility of procuring a satisfactory effluent by this process when the water in question is a highly polluted river water. Whether the process would deal satisfactorily with a sewage effluent of considerable turbidity has not been determined. Rideal points out that ozone is but sparingly soluble. Such being the case, it might altogether fail to penetrate the solid masses in the effluent, since the rate at which a dissolved gas will thus penetrate solids is a direct function of its solubility.

The principal cause of the failure of the ozone process, however, seems to be its expense. If this is the case in water works it seems hardly possible that the process could be applied to sewage effluents as an additional safeguard after purification. There are no data at hand for estimating the cost of ozone treatment when applied to effluents. Besides the cost of treatment there is the very considerable cost of installation of the necessary machinery and towers.

5. CHLORINE AND ITS COMPOUNDS. — Chlorine is well known as a powerful germicide. It has long been known as a bleaching agent acting upon organic coloring matter, not directly, but by means of the free nascent oxygen which it liberates from the water in which it is dissolved. It is probable that its germicidal effect is similar. In other words, chlorine and ozone come to the same thing in the end, namely, nascent oxygen. Chlorine, however, has the advantage of

more ready solubility and of cheapness. It is used technically in three forms, all of which, however, act in the form of free chlorine; and not as compounds.

(*a*) *Chlorine Gas.* — Until within recent years chlorine has been manufactured commercially by the Weldon or some similar process. In the Weldon process hydrochloric acid is made to react with a complex mixture of manganese hydroxide and lime — "Weldon mud" — the reaction being essentially

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2,$$

although in reality it is much more complex.

Recently, however, electrolytic processes have been developed by which the cost of manufacture has been materially reduced, particularly where cheap water power is available. The difficulties in the way of using gaseous chlorine are chiefly the cost of transportation, difficulty and danger in handling the gas, and the difficulty of accurately measuring the amount of gas added to the effluent. On the other hand, if the magnitude of the work would warrant the installation of an electric chlorine generating plant, there is reason to believe that there would be a great economy in the preparation and direct use of the gas, and the disadvantages noted would be obviated to a large extent. This matter of cost will be more fully discussed in another place.

(*b*) *Oxychloride Process. Hermite Process.* — The electrolysis of ordinary salt yields chlorine and caustic soda. It is claimed that if magnesium salts be present, as in sea water, a secondary reaction occurs by which there are produced certain oxides of chlorine. Three oxides of chlorine are known: Cl_2O and Cl_2O_3, the anhydrides of hypochlorous and chlorous acids, respectively, and chlorine peroxide, ClO_2. The latter is formed only under exceptional conditions and is extremely unstable. The others unite instantly with water to form the corresponding acids. There seems to be no legitimate reason for assuming the presence of any compounds in this electrolyzed sea water except compounds analogous to those which we know are produced in the case of the sodium and the calcium salts, namely, hypochlorites. The hypochlorite of magnesium seems to be an unstable compound, readily hydrolyzing to magnesium hydroxide and hypochlorous acid. This fact is sufficient to account for the higher disinfecting value observed in the use of electrolyzed sea water as compared with equivalent amounts of available chlorine in the form of bleaching powder.

Rideal made an extensive series of experiments at Guildford, England, where he was able to test the effect of the "oxychloride" treatment upon raw and septic sewages and upon effluents of primary, secondary, and tertiary contact beds. The following tabulated summary of his results will show about what may be accomplished. By the term "available chlorine" (av. cl.) is meant the chlorine value as obtained by titration with arsenious acid. The results, especially as regards the removal of *B. coli*, are all that can be desired. Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group, aërobic spore-forming bacteria, which are probably beneficial in the further oxidation of the organic matter. Absolute sterilization required very high concentration of chlorine.

TABLE I—SUMMARY OF RIDEAL'S EXPERIMENTS AT GUILDFORD, ENGLAND, ON THE USE OF OXYCHLORIDE IN STERILIZING RAW SEWAGE, SEPTIC EFFLUENTS, AND THE EFFLUENTS OF PRIMARY, SECONDARY, AND TERTIARY CONTACT FILTERS

Sample of	Av. cl. Parts per million.	Time of contact.	Organisms per Cubic Centimetre.					
			Total.		B. coli.		B. enteritidis.	
			Initial.	Final.	Initial.	Final less than	Initial.	Final less than
Sewage	30	4.3 hours	23,000,000	50,000	1,000,000	1.0	1,000	10.0
	50	4.3 hours	23,000,000	20	1,000,000	0.2	1,000	0.2
	70	4.3 hours	23,000,000	10	1,000,000	0.2	1,000	0.2
Septic effluent .	25 to 44	1.0 hour to 4.0 hours	2,500,000 to 4,500,000	20 to 600	100,000 to 1,000,000	1.0 to 0.2	10 to 1,000	1.0 to 0.2
First contact . .	20	40 minutes	. .	. .	100,000	0.2	. .	. .
	20	2 hours	. .	. .	. .	. .	20 to 100	0.2
Second contact .	19.6	. .	1,000,000 to 2,000,000	40	1,000,000	0.2	10 to 1,000	0.2
Third contact .	2.5	1.0 hour	. .	. .	1,000 to 10,000	0.2	. .	. .
	2.5	4.5 hours	. .	. .	. .	. .	10 to 100	1.0
	0.5	0.5 hour	. .	. .	1,000 to 10,000	0.2	. .	. .
	0.5	4.5 hours	. .	. .	. .	. .	10 to 100	0.2

(*c*) *Chloride of Lime.*—Chloride of lime, so called, is a mixture of calcium hypochlorite, calcium chloride, and impurities. Its efficiency as a disinfectant is due to the action of the hypochlorite, which decomposes slowly, giving off oxygen and free chlorine. Thresh has used chloride of lime at Illford, England, for the sterilization of the effluent of a chemical precipitation plant. The addition of 140 to 200 parts of the chloride was found to give a nearly sterile effluent after the latter had flowed in a closed conduit for a mile. Commercial chloride in this country will average 35 per cent. available chlorine. Upon this basis the amount of chlorine used was 50 to 100 parts. The chloride would, therefore, seem to be as efficient as the so-called oxychloride, and in fact is probably a similar compound.

During the past year experiments have been carried on at this station to determine the efficiency of bleaching powder in the sterilization of the effluent of a trickling filter. A preliminary series of tests was first made, covering a wide range of concentrations of bleaching powder. These tests were made in bottles. A strong suspension of bleaching powder was made up and analyzed for available chlorine by the arsenious acid method. Portions of this solution were then measured into bottles, each containing 1 liter of the effluent from the trickling filter. The available chlorine was again determined in a sample withdrawn from the bottle. Determinations of the total organisms present in the effluent before adding the disinfectant and at stated intervals thereafter were made. Plates were made with standard nutrient gelatin, incubated at 20° and counted on the third day.

The results of these tests are summarized in Table II, and in Table III are calculated into percentage figures:

TABLE II — PRELIMINARY TESTS OF EFFICIENCY OF BLEACHING POWDER IN THE STERILIZATION OF A TRICKLING FILTER EFFLUENT

TEMPERATURE 20°

Experiment No.	Bottle No.	Av. cl. Parts per million.	Bacteria per Cubic Centimeter.					
			Initial.	Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
1906								
I. Started February 13 . .	Blank	0.0	80,000	. .	. .	. .	. .	640,000
	1	3.5	70,000	850	. .	500	50	50
	2	10.6	80,000	500	. .	900	290	50
	3	55.0	90,000	50	. .	180	. .	50
	4	108.0	60,000	. .	. .	. .	. .	50
II. Started February 20 . .	Blank	0.0	133,000	. .	. .	. .	. .	. .
	1	25.0	122,000	190	90	. .	. .	. .
	2	25.0	99,000	100	180	. .	. .	. .
	3	37.0	128,000	50	80	. .	. .	. .
	4	100.0	124,000	27	36	. .	. .	. .
III. Started March 7	Blank	0.0	176,000	. .	. .	272,000	. .	. .
	1	2.0	153,000	. .	300	100	. .	. .
	2	5.0	130,000	. .	100	50	. .	. .
	3	5.0	146,000	. .	100	300	. .	. .
IV. Started March 13	Blank	0.0	80,000	. .	. .	86,000	. .	. .
	1	0.25	96,000	. .	33,000	38,000	. .	. .
	2	0.50	84,000	. .	9,100	4,600	. .	. .
V. Started March 29	Blank	0.0	230,000	. .	. .	200,000	. .	. .
	1	1.0	212,000	. .	39,000	1,900	. .	. .
	2	1.5	146,000	. .	500	100	. .	. .
VI. Started April 17	Blank	0.0	24,000	. .	. .	68,000	. .	. .
	1	5.0	25,000	. .	. .	500	. .	. .
	2	10.0	35,000	. .	. .	100	. .	. .

TABLE III — SUMMARY OF PRELIMINARY EXPERIMENTS

Experiment No.	Available chlorine. Parts per million.	Organisms Killed. Per Cent. of Initial Numbers.				
		Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
I	3.5	98.7	. .	97.8	99.6	99.9
	10.6	98.9	. .	98.9	99.7	99.8
	55.0	99.9	. .	99.9	99.9	99.9
II	25.0	. .	99.8	99.9	. .	. .
	37.0	. .	99.94	. .	. .	. .
	100.0	. .	99.97	. .	. .	. .
III	2.0	. .	99.8	99.9	. .	. .
	5.0	. .	99.85	99.9	. .	. .
IV	0.25	. .	65.6	70.9	. .	. .
	0.50	. .	89.2	94.2	. .	. .
V	1.0	. .	81.5	99.1	. .	. .
	1.5	. .	99.6	99.9	. .	. .
VI	5.0	. .	98.2	98.2	. .	. .
	10.0	. .	. .	99.6	. .	. .

These results indicate clearly the practical impossibility of obtaining a sterile effluent in this way. Neither the addition of large amounts of bleaching powder, up to 100 parts of available chlorine per million, nor the storage of the effluent for periods of time up to twenty hours proved entirely effectual. It is further shown that a concentration of about five parts per million of available chlorine and a storage period of about two hours give practically the maximum efficiency possible with the process.

Upon this basis, therefore, a practical test of the process was made. A large trickling filter at the Sewage Experiment Station, filtering raw sewage at the rate of five thousand gallons per day, was used. A solution of bleaching powder was made up in a fifty-gallon barrel of such strength that when added to the effluent at the rate of two gallons per hour it would supply the effluent with about five parts per million of available chlorine. It was not possible on such a small scale to regulate the flow accurately, and there was some variation in the amount of available chlorine found in the effluent This value was determined each day when the samples were taken for bacterial examination. It averaged about five parts per million, and the variation was no more than may be expected in the case of a larger plant with less careful supervision.

The mixed effluent and sterilizing solution passed into a settling basin built on the principle of a Dortmund tank, and designed to give a mean storage of approximately two hours. Regular examinations of the effluent before admixture with the sterilizing solution and after this two-hour period of contact were made. The total bacteria growing upon [illegible] were determined by the usual plating method.

The removal of [illegible] was found to be [illegible] per cent. The [illegible] with presumptive test [illegible] results were obtained [illegible] effluent at [illegible] present in [illegible] centimeter [illegible] 1 c.c. [illegible] pres- [illegible] removal of [illegible] cent.

[illegible] results of this [illegible]

TABLE IV—EXAMINATIONS OF EFFLUENT FROM TRICKLING FILTER BEFORE AND AFTER STERILIZATION WITH CHLORIDE OF LIME, AVAILABLE CHLORINE, FIVE PARTS PER MILLION

Date.	ORGANISMS PER CUBIC CENTIMETER.		GAS PRODUCTION IN BILE BROTH.	
	Before treatment.	After treatment.	Before treatment. Dilution, $\frac{1}{100000}$ c.c.	After treatment. Dilution, 1 c.c.
August, 1906.				
11	270,000	69	+ 0	+ 0
13	630,000	41	0 0	+ 0
14	135,000	406	+ +	+ 0
15	230,000	21	0 0	0 0
16	250,000	37	+ 0	0 0
18	110,000	40	0 0	+ 0
20	90,000	54	+ 0	0 0
21	220,000	22	0 0	0 0
23	. .	. .	+ 0	0 0
Average	240,000	86	33 per cent.	22 per cent.
Average removal		99.96 per cent.		99.993 per cent.

A series of laboratory experiments was carried on at the same time to determine the germicidal power of the bleaching powder solution upon *B. typhosus*. Strong bouillon cultures of this organism were made in sterile tap water. After the number of organisms initially present was determined, suitable amounts of the bleaching powder solution were added, and determinations were made of the organisms remaining alive at stated intervals. The results of these tests are shown in Table V.[1]

---

[1] The writers desire to express their acknowledgments to Dr. R. P. Cowles, of Johns Hopkins University, for valuable assistance in carrying out the bacteriological work involved in these experiments.

TABLE V—EXPERIMENTAL RESULTS SHOWING THE GERMICIDAL ACTION OF BLEACHING POWDER SOLUTIONS UPON B. TYPHOSUS.

Experiment No.	Available chlorine. Parts per million.	ORGANISMS PER CUBIC CENTIMETER.							
		Initial.	One minute.	Twenty minutes.	Forty minutes.	Sixty minutes.	Two hours.	Four hours.	Twenty-four hours.
I	4.2	1,300,000	1,000,000	300,000	59,000	9,800	800	..	15
II	5.4	5,500,000	4,450,000	1,350,000	850,000	675,000	450,000	450,000	6,000
III	4.7	1,200,000	..	465,000	190,000	138,000	50,000	..	54
IV	6.9	3,200,000	20,000	200	..	300	20	..	10
V	3.5	5,800,000	20,000	800	200	500	11	0	1
VI	3.5	3,200,000	70,000	200	100	200	26	16	8

Except in Experiment II, the reduction in twenty-four hours is practically complete, and in two hours is satisfactory for all purposes for which such treatment would be undertaken, the enormous initial numbers being taken into consideration. The phenomenon of a few specially resistant organisms is a very common one in all investigations of germicides, whether of heat, cold, desiccation, or chemical disinfection, and is particularly marked here. The results of Experiment II are in disagreement with the others. Whether they represent a specially resistant culture of the organisms or whether the results are due to some error in the experiment cannot be stated.

Summarizing, it may be said, as a result of these experiments, that a concentration of five parts per million of available chlorine from bleaching powder, acting for a period of two hours, will remove 99.96 per cent. of the total bacteria and practically eliminate the intestinal organism, *B. coli*, and any typhoid organism present.

COST OF CHLORINE IN VARIOUS FORMS

With the electrolytic process in use at Niagara Falls, where cheap power is available, the manufacture of chlorine and of bleaching powder is carried out very cheaply. Commercial bleaching powder can be purchased in the Eastern market at about 1 cent per pound, guaranteed 40 per cent. available chlorine. In other parts of the country the additional freight charges might make the cost somewhat higher. On the convenient basis of 1 cent the actual cost of the chlorine is 2.5 cents, and the cost of adding one part per million of available chlorine to the effluent would be 21 cents per million gallons, or $1.05 per million gallons for five parts. Bleaching powder is made by the action of chlorine upon caustic lime, so that chlorine in this form will obviously cost more than as the free gas. To develop at once its full bleaching or disinfecting action it is necessary to use it in acid solution, as is done in commercial bleaching processes. An investigation of the reactions involved leads us to believe that the total available chlorine, as indicated by the analysis, is eventually set free in a solution of organic matter, such as sewage, especially in the presence of sunlight; but it is probable that the reaction proceeds more and more slowly as it reaches the end, and that in the time available for treatment it is not safe to count upon more than 75 per cent. of the available chlorine being actually used. Rideal observed that there was an immediate loss of available chlorine corresponding roughly to the strength of the sewage or effluent under treatment, and that afterward the loss of available chlorine was very gradual, his explanation being that there were two distinct kinds of organic matter present. With the knowledge that free carbonic acid, always present in sewage, is able to react with the hypochlorite liberating chlorine, we are inclined to the view that the preliminary action noticed was due to this cause. Free gaseous chlorine, on the other hand, is all "available" and ready for immediate use. As the time element is one of immense importance in the design and cost of a sterilization plant, this item alone deserves much weight. Moreover, the use of chlorine gas possesses certain other advantages over the bleaching powder. It adds nothing else to the sewage, whereas bleaching powder adds a certain amount of insoluble material and considerable hardness. It seemed advisable, therefore, to obtain, if possible, some actual cost data on the production of electrolytic chlorine. Through the courtesy of Messrs. A. G. Paine, Jr., president, and J. R. Crocker, superintendent, of the New York and Pennsylvania Company, the following statistics have been obtained, based upon actual costs in a large paper mill using the McDonald electrolytic cell.

Each cell will produce 22 pounds of chlorine and 22 pounds of caustic soda per day of twenty-four hours, with the use of 2.08 kilowatts of current. One kilowatt hour is therefore equal to 0.46 pound of chlorine. The cost of power, made under the most favorable conditions by a modern compound condensing engine, burning "run-of-the-mine" coal at $2 per ton, is estimated at not over $52 per kilowatt year, or 0.6 cent per kilowatt hour. The cost of chlorine is therefore about 1.3 cents per pound, a trifle over half the cost of the chlorine in bleaching powder. If, as we have intimated, this form of chlorine shall be found to be 25 per cent. more efficient than the other, and if the original cost of installation be not too great, it seems that for large works, at least, the manufacture of chlorine might well be undertaken. Even at 2 cents per pound the cost of treating a million gallons of effluent with one part per million of chlorine would be reduced to 16.6 cents, or 83 cents per million gallons for five parts. Moreover, this expense would be considerably offset by the value of the caustic soda produced at the same time.

6. COPPER AND ITS COMPOUNDS. — Rideal has experimented recently with copper salts, and finds them efficient in the sterilization of effluents. While its expense would seem to prohibit the general use of copper, it is undoubtedly a suitable disinfectant for water cress and oyster beds.

Johnson and Copeland (1905) obtained the following reduction of total organisms in effluents:

	Copper sulphate. Rate per million.	Per Cent. Reduction.	
		Three hours.	Twenty-four hours.
First series, average of three sets	5	90.0	99.9
	10	98.0	99.95
	20	98.5	99.96
Second series, average of three sets	10	40.0	99.7
	20	60.0	99.9
	40	88.0	99.95

They find action most rapid during the first hour. They estimate the cost for chemicals alone at $5 per million gallons of effluent, treated with ten parts per million, or $10 for twenty parts, which they consider prohibitive. More experimental data on the use of copper salts are needed before we can judge of their value. Their effect will also depend largely upon the character of the water.

7. MISCELLANEOUS. (*a*) *Permanganate.* — Potassium and sodium permanganate have been used at times for the oxidation of organic matter in streams. At London sodium permanganate is added to the Thames regularly when it becomes too foul at times of low water. The application here is to destroy odors and putrescible material, but it

undoubtedly partially sterilizes the water. Its use has been proposed for rendering effluents of chemical precipitation plants non-putrescible. The cost is greater than chlorine compounds, which would seem to be fully as efficient.

(*b*) "*Amines*" *Process.*—This process was developed by H. Wollheim in England. It is claimed that trimethylamine treated with lime or other alkali produces a very poisonous substance. Herring brine is used for the amine. A large excess of lime is used, and the mixture used to precipitate crude sewage. Klein made a test of the process at West Horn in 1889, and found that a clear, non-putrescent, and sterile effluent could be obtained. Similar results were obtained at Wimbledon, where the bacteria on the sewage were reduced from 768,000 to none. The sludge is also non-putrescible. The process has never been developed further. (Great Britain, 1902, A, Quest. 5206.)

CONCLUSIONS

Summarizing the more important points of the present discussion, we may state:

Ordinarily it is not the function of the sewage filter to remove bacteria from the sewage. In the case of the modern rapid filters, we are not at all certain as to the fate of the dangerous germs of disease.

Where extensive shellfish interests are at stake it will sooner or later become necessary to protect the neighboring waters from pollution, and in this case the total absence of pathogenic bacteria must be assured.

This result may be attained by the ultimate use of sand filters or by chemical sterilization.

Among the possible agents for use in sterilization, chlorine, either as chloride of lime or as free gaseous chlorine, appears to have the highest cost efficiency. An amount of the former which will yield five parts per million of available chlorine was found to have destroyed 99.96 per cent. of the total bacteria and practically all of the *B. coli* present in the effluent of a trickling filter treating crude Boston sewage, the time of contact having been two hours. The estimated cost of such treatment is $1.05 per million gallons of sewage.

The use of gaseous chlorine, manufactured at the disposal works by electrolytic methods, would in the case of larger works considerably reduce this cost. An approximate estimate places the cost of such treatment at about 85 cents per million gallons of sewage, allowing five parts of chlorine per million. It is probable that the chlorine in this form is somewhat more efficient.

The process as thus outlined is entirely feasible, and in the case of large works it is cheaper than sand filtration. Further experiments upon a large scale are now under way to test the results of these experiments and to get more accurate cost and efficiency data.

Among other agents which may be used, copper sulphate seems to be the most promising, and further experimental data are needed to show what efficiency may be expected from its use.

REFERENCES CITED

Baltimore, 1906. Report of the Board of Advisory Engineers and of the Chief Engineer on the Subject of Sewage Disposal. Made to the Sewerage Commission of the City of Baltimore.

Fuller, G. W., 1905. Concerning Sewage Disposal from the Standpoint of the Pollution of Oysters and Other Shellfish, with Especial Reference to Their Transmission of Typhoid Fever. Jour. Frank. Inst., CLX, p. 82.

Great Britain, 1902, A. Interim Report of the Royal Sewage Commission, London.

Great Britain, 1902, B. Second Report of the Royal Sewage Commission.

Great Britain, 1904. Fourth Report of the Royal Sewage Commission.

Jackson, D. D., 1906. A New Presumptive Test for *B. Coli.* Biological Studies by the Pupils of William Thompson Sedgwick, p. 292.

Johnson, G. A., and Copeland, W. R., 1905. Copper Sulphate as a Germicide. Jour. Inf. Dis., I, Supplement No. 1, p. 327.

Massachusetts, 1906. Annual Report of the Massachusetts State Board of Health for the year 1905, Boston.

Rideal, S., 1905. On the Sterilization of Effluents. Jour. Roy. San. Inst., XXVI, p. 378.

Winslow, C.-E. A., 1904. The Number of Bacteria in Sewage and Sewage Effluents Determined by Plating upon Different Media and by a New Method of Direct Microscopical Enumeration. Jour. Inf. Dis., I, Supplement No. 1, p. 209.

[Reprinted from TECHNOLOGY QUARTERLY, Vol. XX, No. 3, September, 1907]

CONTRIBUTION FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE PREVENTION OF STREAM POLLUTION BY STRAWBOARD WASTE[1]

BY EARLE BERNARD PHELPS

INTRODUCTION

THE disposal of the waste liquors resulting from the manufacture of strawboard forms one of the most important problems connected with the prevention of stream pollution. In 1900 the total production of strawboard in the United States was 157,534 tons at 59 factories. For each ton of strawboard manufactured there were discharged into the streams about 65,000 gallons of waste liquor that contained 1,173 pounds of straw and mineral matter and 490 pounds of lime. The total waste discharged into the streams in 1900 amounted to 10,239,710,000 gallons of liquor, containing 184,777,382 pounds of straw and mineral matter and 77,191,660 pounds of lime. This enormous waste was discharged by 59 plants of various sizes, but as most of these mills are along small streams the resulting pollution is very apparent. Some idea of the amount of this pollution may be obtained from Plate I, *B*. The baled straw shown is a three months' supply for a mill having an output of 30 tons a day. In three months one-third of this straw will be discharged into the stream as waste matter.

The problem of the disposal of the waste water has been studied by Professor R. L. Sackett, of Earlham College,[2] and the present investigation is a continuation of the work of Sackett along new lines. In approaching the problem it is necessary to keep constantly in mind the economic conditions affecting the industry. The low selling price of the

---

[1] Reprinted by permission from Water-Supply and Irrigation Paper, No. 189, United States Geological Survey.

[2] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 9–35.

PLATE I

A. VIEW OF STRAWBOARD MILL

B. PILES OF BALED STRAW

One-third, by weight, will be wasted in three months product, the immense volume of waste water necessary, and the fact that competition between strawboard and other forms of cheap board is active, make it quite impracticable for the manufacturers to adopt any process involving serious expenditures. The solution of the problem must be sought in a process which will show an actual saving. Aside from the matter of the recovery of by-products of commercial value, this means that the process must compete in cost with the present unsatisfactory sedimentation methods employed at many of the mills, to the cost of which may reasonably be added the almost constant expense of lawsuits and injunction proceedings, the latter in some cases causing the closing of the mill.

As a result of this study it has been found that sedimentation of the waste water for a short period, followed by filtration thru sand at high rates—the so-called mechanical filtration, but without coagulants—will produce an effluent from which more than 90 per cent. of the suspended organic matter has been removed. This effluent, while not ideal, is probably purified to such an extent that, allowing a factor of safety of 2 for impurities in the stream, it may be discharged into streams having a minimum flow of twice the discharge of the mill without producing a nuisance. The cost of filtration by this process, after the initial cost of installation, is practically reduced to the cost of pumping the wash water. The final result is a heavy sludge, whose volume is less than 5 per cent. of the initial volume of the waste. Ultimate disposal of this sludge could be made either by discharge over land for spontaneous evaporation, by evaporation by means of artificial heat, or by filter pressing. The sludge has some value as a fertilizer, and there are also certain commercial uses to which it seems to be adapted.

THE MANUFACTURE OF STRAWBOARD

The following description of the manufacture of strawboard is taken from Professor Sackett's paper:[1]

Steaming in Rotaries

"The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a 'rotary' . . . is filled with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. . . . This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark yellow, pulpy mass. This 'stock,' as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the *Journal of the Society of Chemical Industry*[2] says:

---

[1] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 13–15.

"'The chemical action of the milk of lime on the incrusting materials surrounding the straw fiber is not a vigorous one. These incrusting materials are not completely, nor, indeed, to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water.'

"The yield of pulp at this point will be from 75 to 80 per cent. of the weight of the original material. . . .

"The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent. of water and from 6 to 7 per cent. of lime. This is equivalent to from 12 to 14 per cent. of lime in the dry straw. Since the original charge of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent. lime, practically none of the latter has drained out with the condensed steam. This drainage [illegible] but a small part of the waste sewage. [illegible] carrying a small quantity of fiber [illegible]

[illegible]

[illegible] the great [illegible]

[illegible]

"The stock is run thru washing machines for the purpose of removing the lime. . . . The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, thru which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times thru the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. . . .

DRYING

"After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats, where it is mixt with large quantities of water and past over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are prest down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in thru hollow bearings. As the pulp passes on thru the train it is constantly prest and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent. of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish."

THE DISPOSAL OF WASTE LIQUOR

Method in Use

At present, so far as can be learned, the only method of treating the waste liquor in actual use by the manufacturers is that of prolonged sedimentation in open fields. The overflow water from these fields is not satisfactorily clarified at all times of the year. During cold weather it is fairly clear and can be discharged without serious harm. During the summer, however, a very offensive fermentation takes place in the accumulated sludge, giving rise to objectionable odors and blackening the water. At such times the aim is to hold all the waste water in the ponds, trusting to evaporation and to the storage capacity of the ponds until cold weather again relieves the situation and the increased flow of the stream permits a discharge of the surplus water stored. The most serious objection to this process, which seems to be satisfactory to riparian owners below, is the fact that these ponds are continually filling up with a soft mud, which destroys their function as sedimentation basins and renders them useless for other purposes. The time must come, even in the most favorable situation, when additional land cannot be afforded for this purpose. A second objection is that the accumulated sludge is held for years and slowly putrefies. The organic matter of the waste is but slightly nitrogenous and is fairly stable. It probably contains some reducing sugars capable of rapid fermentation if kept in concentrated form and if given at the same time some nitrogenous matter. The slow decomposition of the stable straw material supplies the necessary nitrogen, and the result is a very rapid multiplication of the putrefactive organisms and an accompanying offensive putrefaction. Laboratory experiments have shown that the soluble sugars by themselves, as found in a filtered sample of the waste water, do not ferment or decompose, and that even the unfiltered waste is not subject to a quick putrefaction such as characterizes sewage matter. In fact, bottles have been stored for over a year without any evidence of fermentation, and it may very reasonably be held that the necessary nitrogen comes largely from the bottom of the ponds, rather than from the sludge itself. Inspection of the stream below one of these ponds showed that, while putrefaction was barely noticeable and not at all offensive in the pond itself, the admixture of some of this water with that of a small brook, highly polluted with the refuse of a slaughter-house, had immediately a very offensive result. Investigation of the condition of the streams below these mills reveals the fact that the most serious nuisance generally occurs at a point very remote from the mill itself. It is directly caused by the slow decomposition of material deposited in the bed of the stream. The conditions are doubtless aggravated by the simultaneous precipitation of other polluting substances, notably sewage, brought about by the free lime of the strawboard waste.

The effective solution of the problem lies in the rapid separation of the solid matter from the dissolved sugars and lime and a subsequent dilution of the latter so that they shall be innocuous. The insoluble material when dry is entirely stable. The present system, therefore, is not only unsatisfactory from the economic side, but it works on a wrong principle for satisfactory purification in that it encourages putrefaction.

The cost of these ponds at four of the larger mills of the United Box-board and Paper Company, as stated by an official of that company, has been, in round numbers, to date, $10,000, $15,000, $18,000, and $8,000. In the last case the results were still unsatisfactory, and after a considerable expenditure on other experiments the company has been obliged to close this mill.

PROPOSED METHODS

Centrifugal Separation

Centrifugal separation of the solid matter from the liquor was tried at Tiffin, Ohio, in 1904. It has not been possible to obtain more definite information concerning those experiments than is contained in the trade papers of that time. It is understood, however, that the results were quite satisfactory, but that the cost of operation was prohibitive. The account referred to (see *Paper Trade Journal*, February 2, 1905) states that the effluent was clear and colorless and that the residue was found by analysis to be valuable as a fertilizer.

Precipitation with Carbon Dioxide

As a result of his investigations Sackett concluded that plain sedimentation would remove about 10 per cent. of the suspended solids in twenty-four hours, and that during the ensuing twenty-four hours the additional removal was very slight; that good purification could be effected by chemical precipitation only by using sulfate of aluminum in excessive amounts and at an entirely prohibitive cost; that sulfate of iron gave inferior and unsatisfactory results; and, finally, that by a process of precipitation with carbon dioxide and lime an average removal of 85 per cent. of the suspended matter could be effected.

The process recommended by Sackett consists in (*a*) saturation of the waste water with carbon dioxide to form bicarbonate with all the lime present; (*b*) addition of lime equal to that already present to form a normal carbonate; (*c*) sedimentation of the precipitated carbonate and consequent dragging down of some of the organic matter; and (*d*) filtration of the resulting clarified liquor thru sand at rates of 500,000 to 2,000,000 gallons per acre per day. This process has never been used by manufacturers so far as the writer is aware.

It does not appear from Sackett's report that he tried the simpler but equivalent process of saturating one-half the total volume with carbon dioxide and then mixing with the other half. Such treatment would doubtless have precipitated the calcium fully as well, with a saving of one-half the carbon dioxide and all the lime required by the process recommended. An examination of the analytical data shows that the removal of suspended organic matter accomplished by the precipitation and sedimentation processes varied from zero to 75 per cent., with a mean value of 37 per cent. Experiments on plain sedimentation, made by the writer both in the laboratory and on a large scale in the field, show it to be equally efficient for the removal of suspended organic matter. The fact is that the precipitated carbonate of calcium is very finely divided and has no value as a coagulant. The process is valuable to remove the lime, if that be desirable. It hardly seems, however, that the value of discharging a lime-free effluent into the hard waters of the Middle West is at all commensurate with the cost of treatment.

LABORATORY INVESTIGATIONS

CHEMICAL STUDY OF THE SOLUBLE MATTER

Several barrels of the strawboard waste liquor were shipped to Boston from one of the mills of the United Box-board and Paper Company, and on this material a series of investigations was carried out. Sackett's experiments with various coagulants were repeated and his results confirmed. It was found that the poor results obtained with any but excessive amounts of iron or aluminum sulfate were due to the presence of a substance in solution which forms soluble combinations with those metals. This substance was isolated by precipitation with hydrochloric acid, and after repeated purification was found to have the following properties: It is an organic acid, probably related to the humic or ulmic acids of the soil and peaty waters. It exists in the waste water as a calcium salt, having partially neutralized the free lime used in the digestion. It is precipitated by strong acids, coming out as a dark-red substance which turns brown on slow oxidation in the air. It can be redissolved in a solution of sodium carbonate, giving a garnet-red solution. It dissolves in alcohol, giving a deep-red color, but oxidizes to a brown, insoluble substance. Its calcium and aluminum salts are not soluble when prepared from the insoluble acid, but the acid cannot be precipitated from its solutions by these metals. It appears that there are formed colloidal suspensions of the calcium and aluminum salts. The solutions have a bright yellow color and colloidal appearance. The iron compound is similar but of a green color. The sodium salt appears to be soluble and to dissociate into deeply colored acid ions.

A second substance isolated from the waste has the following properties: It is soluble in water and not precipitated by any of the common precipitants, including alum, ferrous sulfate, lead acetate (normal or basic), carbonates, hydrates, or acids. It is responsible for a large part of the color of the water and cannot be removed by any practical method.

These two substances with the lime make up the greater part of the dissolved material. They are entirely stable and do not undergo putrefactive change when stored in the incubator, either alone or mixt with varying proportions of tap water. In addition to these substances small amounts of reducible sugars are present. The amount is so small that in any material dilution of the liquor the dilution of these sugars will prevent their manifesting themselves as putrefactive agents. These sugars are probably responsible for the slow fermentation in the sedimentation fields after the lime has been sufficiently removed to allow the action to proceed.

PRECIPITATION EXPERIMENTS

Substances in suspension may be removed by filtration or by sedimentation. When the material is finely divided or of low specific gravity, either process may sometimes be assisted by the application of suitable coagulants. These tend to clot the small particles into larger flakes, and by their own greater density carry the clotted material to the bottom. Two chemical substances are required, as a rule, to produce the necessary precipitation, one of which is generally the calcium bicarbonate found normally in the water. This calcium salt reacts with the sulfates of certain metals, notably iron or aluminum, to produce the sulfate of calcium and the hydrates of the corresponding metals. In the present case there is a large amount of free lime in solution. It would seem, therefore, that precipitation might be brought about by the addition of either copperas or alum. Experiments showed that copperas failed to react at all and that fair results could be obtained with alum, but only at a prohibitive cost. As will be seen in the accompanying tables of results, the removal of organic matter by alum was much better than that obtained by plain sedimentation.

RESULTS OF PRECIPITATION EXPERIMENT ON STRAWBOARD WASTE

Sample.	Suspended Solids.	
	Present.	Removed.
	Parts per million.	Per cent.
Raw waste	1,350	. .
Waste after two hours' sedimentation:		
With coagulant *	120	91
Without coagulant	560	59

* The coagulant used was alum in the proportion of 10 grains of sulfate of aluminum per gallon.

Increasing the amount of aluminum sulfate gave practically the same result. Smaller amounts gave indefinite and at times negative results. The use of 10 grains per gallon of sulfate of aluminum at 1 cent a pound would represent a cost of about 43 cents per ton of finished product of the mill. The studies on the nature of the dissolved material already referred to explain these poor precipitation results with alum. Soluble compounds are formed with the organic acid, instead of aluminum hydrate, the desired coagulant.

Experiments were made with carbon dioxide according to Sackett's procedure, and his results were confirmed. There was but a slight removal of suspended organic matter—about 30 per cent.—which could be produced equally well by plain sedimentation. In fact, under actual working conditions sedimentation was found to be even more effective.

Sedimentation Experiments

In a study of plain sedimentation it is important to know the rate of sedimentation and how this varies with the time. With satisfactory data on this point it is possible to estimate the amount of clarification which may be expected to result from any given period of sedimentation, and to establish the most suitable period for the case in hand. It was observed early in this work that apparently a large portion of the suspended solids settled out in a very short time, and that to all appearances further improvement was extremely slow. The determinations of the total solids given in the following table show that there is no practical advantage in sedimentation for a period of much over one hour.

Effect of Sedimentation on Strawboard Waste

	Suspended Solids.	
	Present.	Removed.
	Parts per million.	Per cent.
Liquor at beginning of experiment	1,344	. .
Supernatant after one hour	548	59
Supernatant after twelve hours	494	63

Summary

As a summary of the laboratory investigations, it may be said that the removal of the dissolved coloring and other organic matter and the lime in an economical way is impractical; that by plain sedimentation a removal of suspended material practically as good as the best removal observed with the use of a coagulant can be accomplished; and that a sedimentation period of one hour is sufficient for the removal of about 60 per cent. of the suspended solids, a longer period increasing this removal but slightly. For the removal of the remainder of the suspended matter there remains but one process—filtration. It was therefore decided to make an actual field test of this method of purification. The very large amounts of suspended matter to be handled seemed to eliminate at the outset the possible use of slow sand filtration, so that it was obvious that mechanical filtration at high rates and with some provision for removing the accumulated sludge from the surface of the filters was the only system applicable to the problem.

FIELD INVESTIGATIONS

ACKNOWLEDGMENTS

In March and April, 1905, a visit was made to one of the mills of the United Box-board and Paper Company, at Urbana, Ohio. Every opportunity was given the writer to make a thoro study of the processes of manufacture, and it is here desired to make suitable acknowledgments to Mr. Rush E. Evans, division manager, and to Mr. D. C. Amerine, superintendent, for the many courtesies extended, both on that occasion and during the subsequent visit for the installation of an experimental plant.

AMOUNT OF WATER USED

It was found that conditions were favorable for measuring the entire volume of waste water, as it left the mill in a waste flume. As a check on these measurements, observations of the rate of operation of the pump were made, all the water used being pumped from a large well under the mill.

A rectangular flume, whose mean width was 1.96 feet, was used for these measurements. A distance of 100 feet was measured off in a portion where the slope was practically constant. To determine the velocity of flow at various elevations in the flume, a float was used which was nearly as long as the width of the flume and was provided with vanes underneath, so that it always floated squarely across the flume. The following observations are the mean of a large number made at various elevations of water in the flume.

MEAN DEPTH, VELOCITY, AND FLOW OF WASTE WATER IN FLUME OF MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO

Depth of water.	Velocity of flow	Area of cross-section.	Flow.
Feet	Feet per second	Square feet.	Cubic feet per second.
.19	3.1	.37	1.1
.25	3.8	.49	1.9
.29	4.0	.57	2.3
.31	4.2	.61	2.6
.33	4.3	.65	2.8
.37	4.5	.73	3.2

These values of the depth and the corresponding flow were then plotted. The most probable line was drawn thru them, and that curve was used as the true rating curve of the flume in the subsequent calculations.

During the two hours from 10.45 A.M. to 12.45 P.M., March 30, a test run was made to determine the total flow. The following readings of the elevation of the water in the waste flume were made, and from these readings has been calculated the total flow for the two hours.

Flow of Waste Water in Flume of Mill of United Box-board and Paper Company, Urbana, Ohio, March 30, 1905

Time.	Depth.	Flow.	Flow for Fifteen-Minute Period.	
			Mean rate of flow.	Total flow.
	Foot.	Cubic feet per second.	Cubic feet per second.	Cubic feet.
10.45 A.M.	.29	2.3	. .	. .
11.00 A.M.	.29	2.3	2.3	2,100
11.15 A.M.	.33	2.8	2.6	2,300
11.30 A.M.	.33	2.8	2.8	2,500
11.45 A.M.	.33	2.8	2.8	2,500
12.00 M.	.33	2.8	2.8	2,500
12.15 P.M.	.38	3.4	3.1	2,800
12.30 P.M.	.36	3.1	3.2	3,000
12.45 P.M.	.33	2.8	3.0	2,700
Total	. .	. .	. .	20,400

This total flow of 20,400 cubic feet in two hours represents an average flow of 2.69 cubic feet per second.

A few measurements were made of the water running in the waste flume when the beaters were not running and again when the paper machine was stopt. The flow from the machine was found to be fairly constant at 1.4 cubic feet per second, and the beaters were found to discharge amounts of 1.2 to 1.8 cubic feet per second, depending on the number of beaters in operation at the time.

During the test run observations of the rate of operation of the pump were made at short intervals. The pump was a double-acting duplex Smith-Vaile pump, with water cylinders 14 inches in diameter and with a stroke of 15 inches. Slip being neglected, the capacity of the pump is, therefore, 1.335 cubic feet per stroke, or 5.340 cubic feet per complete revolution. Following are the observations made on the pump and the calculated rate of pumping:

DISCHARGE OF PUMP AT MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO, MARCH 30, 1905

Time.	Revolutions per minute.	Discharge.	Time between observations.	Discharge of Pump between Observations.	
				Mean.	Total.
		Cubic feet per second.	Seconds.	Cubic feet per second.	Cubic feet.
10.45 A.M.	31	2.28	. .	. .	. .
11.00 A.M.	30	2.67	900	2.43	2,457
11.15 A.M.	30	2.67	900	2.67	2,403
11.30 A.M.	30	2.67	900	2.67	2,403
11.45 A.M.	30	2.67	900	2.67	2,403
11.55 A.M.	30	2.67	600	2.67	1,602
11.55 A.M.	40*	3.58	. .	. .	. .
12.25 P.M.	40	3.58	1,800	3.58	6,444
12.45 P.M.	38	3.57	1,200	3.48	4,176
Total pumped	. .	. .	. .	. .	21,888

* Changed

During the test four of the seven rotaries were filled. Two hundred and fifty cubic feet of water are required for each rotary, or 1,750 cubic feet for the seven. Since all seven are filled only once in twenty-four hours, the water used in this process amounts to 73 cubic feet per hour for the whole day. The water used during the two hours of the test was, however, [illegible] cubic feet over the normal [illegible] therefore. be corrected [illegible] the supply tank was [illegible] start. The [illegible] therefore, to [illegible] stream of water was being wasted from the engine condenser. This stream was roughly estimated by float measurements to be about 0.3 cubic foot per second, or 2,160 cubic feet during the two hours of the run. These three corrections amount to 2,888 cubic feet, which is to be subtracted from the total pumped, 21,888 cubic feet, leaving a net pumpage of 19,000 cubic feet for two hours, or 2.64 cubic feet per second, a result in close agreement with the 2.69 cubic feet per second measured in the waste flume.

Raw Material and Finished Product

During this test run, careful weighings were made of the amount of finished board produced. The figures were as follows:

Product of Mill of United Box-board and Paper Company,
Urbana, Ohio, for Two Hours, March 30, 1905

	Pounds
Gross product	4,841
Waste and trimmings	196
Net product	4,645

Dividing the total amount of waste liquor, 20,400 cubic feet, by the amount of net product gives 8,780 cubic feet, or, roughly, 65,000 gallons per ton of product. As the daily product of this mill is about 30 tons, about 1,900,000 gallons of waste water are discharged each day.

The charge of one rotary was carefully weighed. There were used 133 bales of straw, of an average weight of 102 pounds, or a total of 13,600 pounds of straw. The amount of lime was weighed, but the weight was somewhat in excess of the average amount used, as determined by the total weekly consumption of lime. The latter figure, which is 2,100 pounds per charge, will therefore be used. The total amount of straw used in the 7 rotaries is accordingly 95,200 pounds per day, and of lime, 14,700 pounds per day. Subtracting from this the 60,000 pounds of finished product leaves a waste of 35,200 pounds of vegetable and mineral matter from the straw and 14,700 pounds of lime, which is carried off each day in the 1.9 million gallons of water. Calculated into parts per million, these figures give about 2,400 parts of straw material and about 1,000 parts of lime. Analyses of average samples of the waste water gave about 600 parts of calcium or 840 parts of lime per million. The difference is due partly to the loss of lime during the draining of the digested pulp and largely to impurity of the lime.

CHARACTER OF THE MACHINE WATER

Determinations of the lime were made on the well water and on the various waste waters. It was found that the greater part of the lime is washt out in the beaters, and that the water from the machine contained but little lime in excess of that in the raw water. The actual figures were:

CALCIUM IN WASTE WATER

(Parts per million)

Well water	238
Beater water	1,164
Machine water	380

A rough determination of the impurities was made by precipitating the lime and organic matter, with a large excess of alum. A 6-inch column of the beater water gave a layer of precipitate an inch thick, while the amount obtained from the machine water was too small to be measured.

MECHANICAL FILTRATION

In May, 1906, a small experimental filter was installed at this mill, in order to obtain some practical data on the efficiency of treating the waste by mechanical filtration. The filter and accessories were loaned by the New York Continental Jewell Filtration Company, of New York, thru the courtesy of Mr. R. E. Milligan, assistant general manager, and the expenses of shipment and installation were borne by the paper company.

Description of the Filter

The filter used is shown in Figure 1. The waste water, after passing the regulating butterfly valve, divided into two streams and entered the bottoms of the two sedimentation tanks. These tanks were of cypress, each having a diameter of 4 feet and a depth to the overflow line of 3.2 feet. The capacity of the two was 603 gallons. The water was delivered to the tanks thru half-inch holes in the sides of risers extending to the surface. The vertical distribution was, therefore, very uniform. Vertical baffles caused the water to flow completely thru the tanks, and a funnel-shaped overflow collected the clarified water from the surface of each tank and delivered it to the surface of the filter. The filter proper was of galvanized iron, set upon a cast-iron base, provided with a false bottom of fine brass screening. The diameter of the filter was 20 inches and its total depth to the false bottom was 5 feet. Suitable

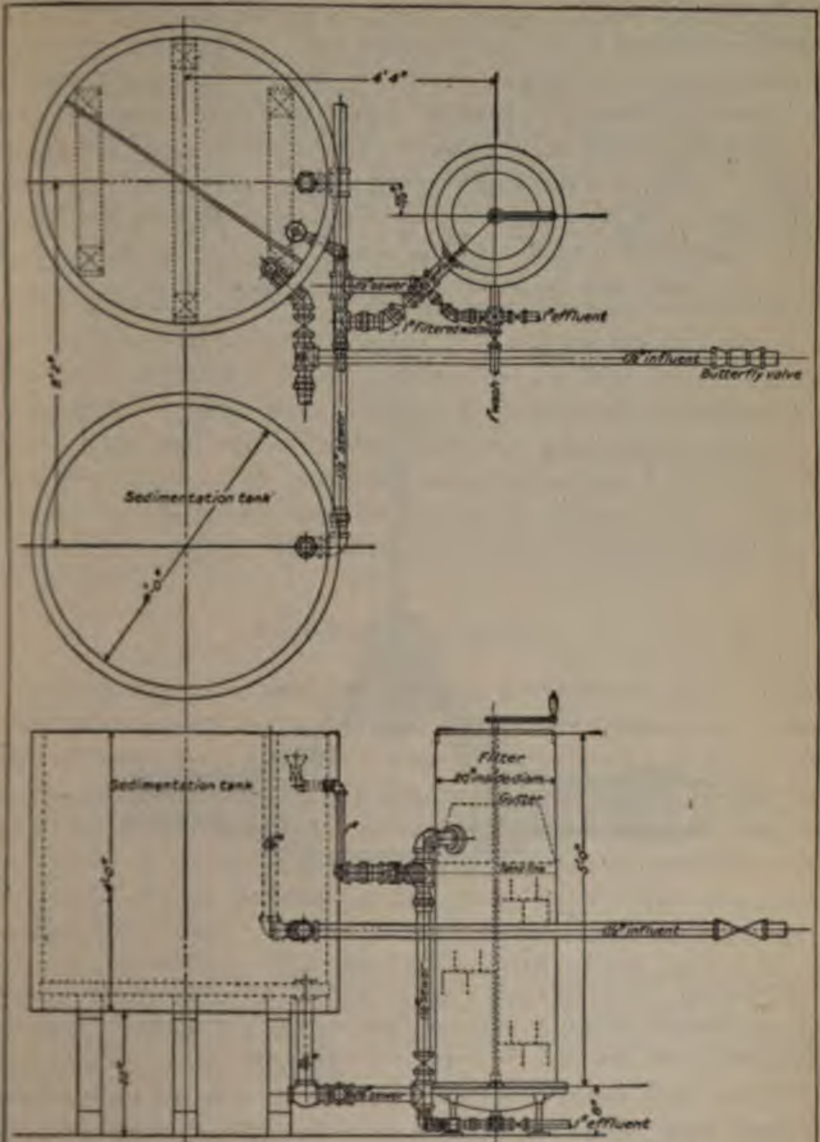
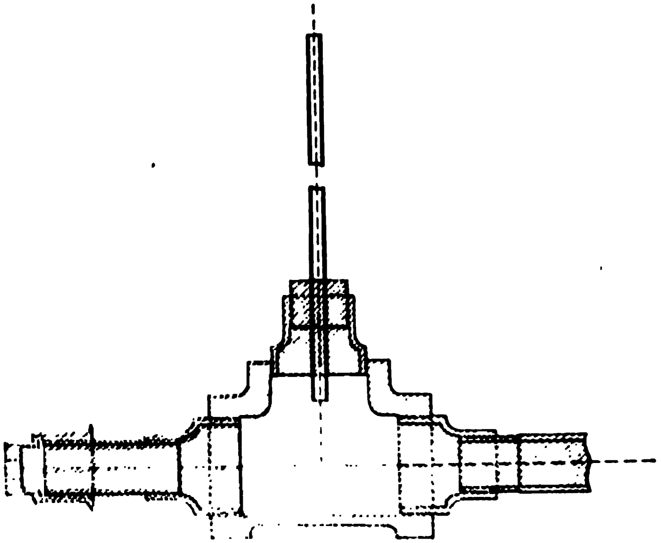


FIG. 1—THE FILTER

connections and valves were provided, as shown in the drawing, so that the influent and the effluent water could be cut off, a stream of wash water could be admitted from the bottom, and the dirty wash water, overflowing from the top, could either be wasted thru the sewer connection or returned to the sedimentation tanks. The device for stirring the sand during washing was operated by hand. Wash water was supplied from an elevated tank under such a head that a maximum flow of 25 gallons per minute, or 12 gallons per square foot per minute, was possible. A flow of about 8 gallons per square foot per minute was generally used. Suitable connections were also made between the bottoms of the sedimentation tanks and the sewer. A 50-gallon barrel at the end of the sewer line served as a measuring tank for the wash water



[illegible]

[illegible] was regulated at the out- [illegible] in Figure 2. [illegible] inch in diam- [illegible] over a nipple [illegible] tee. The [illegible] valve regu- [illegible] of the [illegible] The [illegible] orifice [illegible] device [illegible] indicated in the [illegible] calibrated by discharging into a large measuring tank. The rough field values were found to be substantially correct.

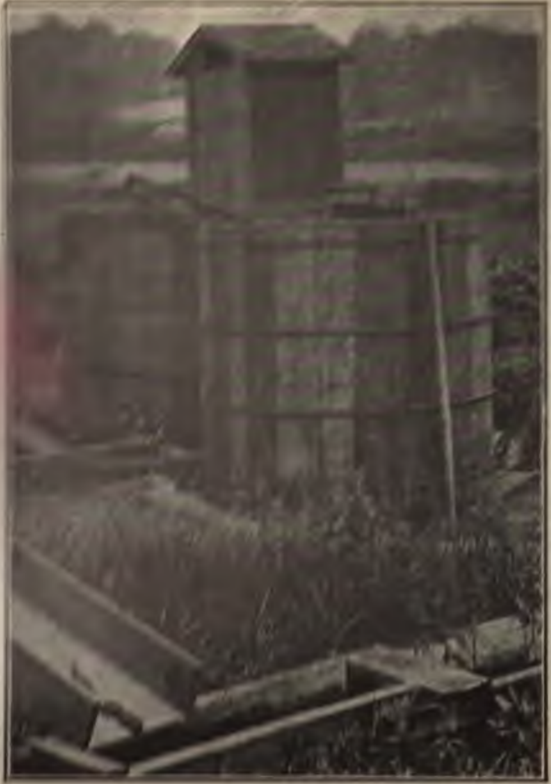
The rate of inflow to the tanks was adjusted to the rate of filtration by the butterfly valve, actuated by a float in one of the tanks (not shown). The filter was filled to a depth of 3 feet with clean 16–30 beach sand, *i.e.*, sand which will all pass a screen with 16 meshes to the linear inch and be retained on a screen with 30 meshes. The water line was 18 inches above the surface of the sand.

The appearance of the filter and sedimentation tanks as they were set up is well shown in Plate II. Plate II, *A*, shows the sedimentation tanks, the influent pipe and controlling valves, and the lever arm of the float operating the butterfly valve. Plate II, *B*, shows the filter itself, the loss-of-head gage, and the connections with the tanks and the sewer. To the extreme right is the measuring tank, and passing between the two tanks on the ground the wash-water pipe line can be seen. The outlet of the filter is hidden from view behind the mound of earth in the foreground.

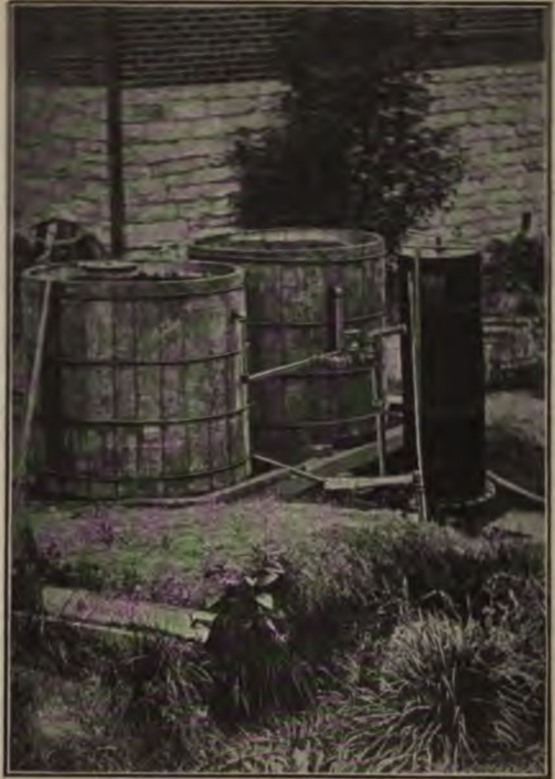
Preliminary Sedimentation

A number of tests were first made to determine the rate of change in the loss of head during filtration with varying periods of preliminary sedimentation. A uniform rate of filtration of 3.25 gallons per minute, equivalent to a rate of 100,000,000 gallons per acre per day, was maintained. The capacity of each of the sedimentation tanks was 300 gallons to the overflow line, so that one tank alone gave a mean storage capacity of one and one-half hours and the two tanks taken together three hours. During the first series of tests both sedimentation tanks were used. The following table shows the relation of loss of head to the quantity of water filtered, the run in question being a fair average of the five made in this way. The results of all the five tests were practically identical.

PLATE II



A. Sedimentation Tanks and Float Regulator



B. Experimental Filter, Sedimentation Tanks, and Measuring Tank

RELATION OF LOSS OF HEAD TO QUANTITY OF WATER FILTERED

Time.	Elapsed time.	Quantity filtered.	Loss of head.
	Minutes.	Gallons.	Inches.
9.35 A.M.	.	. .	4
9.50 A.M.	15	49	7
10.05 A.M.	30	98	8
10.30 A.M.	55	178	12
1.40 P.M.	55	178	11
2.00 P.M.	75	211	14
2.30 P.M.	105	308	20
3.00 P.M.	135	406	28
3.30 P.M.	165	504	40
4.00 P.M.	195	600	55

Between 10.30 A.M. and 1.40 P.M. test shut down. No liquor.

The maximum loss of head possible was 55 inches. The mean results from the above and four similar tests gave 585 gallons of water filtered before the loss of head was total.

One of the sedimentation tanks was then cut out of service and the period of sedimentation correspondingly reduced to one and one-half hours. Four runs to determine the maximum amount which could be past under the conditions gave a mean result of 575 gallons, in practical agreement with that of the first series. It is apparent that a period of one and one-half hours was sufficient for the removal of that portion of the suspended matter which can be removed by sedimentation. An examination of the water during sedimentation in a glass vessel tended to confirm this conclusion. The suspended matter appears to be of two distinct kinds. One is very finely divided and light and does not settle out even on prolonged sedimentation. The other is granular and heavy and settles rapidly and completely. It was not convenient with the apparatus at hand to reduce further the period of sedimentation. The laboratory experiments quoted earlier in this paper indicated that a period of one hour would accomplish practically the same result as more prolonged sedimentation.

Amount of Wash Water

The pressure on the wash-water pipe line was sufficient to give an upward flow thru the filter of 25 gallons per minute, or about 12 gallons per minute per square foot of surface. In practise, flows of 8 to 10 gallons per square foot per minute were used. After each of the test runs just described, the filter was washt with an amount of water varying from 50 to 100 gallons for two and one-half to five minutes, the wash water being carefully measured. Observations of the surface of the filter showed plainly that the shorter period of washing was sufficient and that the longer periods did not in any case increase the quantity filtered during the succeeding run. The material deposited on the surface was exceedingly light and finely divided, and required but little water for its removal. The stirring device used was not well adapted to the purpose, since there was little penetration of the sand by the suspended material. An air blast or some device which would thoroly agitate the surface before washing would undoubtedly make possible the use of still less wash water. Allowing 50 gallons for each wash, with an average quantity of 575 gallons per run filtered, gives a little less than 9 per cent. wash water.

The loss of head in these tests bears out a fact of general observation, that the loss of head increases at a fairly constant rate during the run. Such being the case, it is quite evident that with a deeper filter the quantity filtered between washings would be proportionately increased. The amount of wash water would, on the other hand, remain constant or increase but slightly. It is therefore safe to say that with a filter having an available loss of head of 9 to 12 feet an average run of six hours or more could be maintained and the amount of wash water could be reduced to less than 5 per cent.

Disposal of Wash Water

The process, as thus far described, is merely one of concentration of the suspended matter. If the above estimate of 5 per cent. of wash water be correct and the filtered water be used for washing, the net result of the process would be the separation of 95 per cent. of the water in comparatively clear form, leaving the total suspended impurity in the remaining 5 per cent. of the water. This water might be spread upon a small area of land to evaporate, or might be evaporated by artificial means or, if preferable, it might be [illegible], but the most economical way to dispose of it is to return it directly to the sedimentation tanks. The material on the filter is so prest together into small lumps that it settles rapidly. The problem of the ultimate disposal of the sludge from the tanks will be taken up in another place.

Character of Effluent

Complete chemical analyses of the waters before and after treatment during these experiments were neither desirable nor feasible. The determination of the total organic solids contained in the waters is the only analytical determination which would be of service in estimating the efficiency of the process. This determination might have been made by the usual indirect method, *i. e.*, by the difference between the total and the fixt or mineral solids. That determination is, however, not well adapted to field conditions, and small changes in the organic content would be entirely masked by the relatively large amount of mineral residue present. It was found in the laboratory studies on the waste liquor that estimating the efficiency of the various precipitation methods on the basis of this organic-solids determination, and also on the basis of the oxygen-consumed method, gave practically the same results. In other words, the organic matter present is fairly homogeneous in character, as might well be expected, and the oxygen-consumed figures, altho purely relative, are therefore a reliable measure of the amount of organic matter present. This test, therefore, and the determination of the turbidity, or suspended solids, by the well-known Jackson turbidimeter method, were used in this work to determine the quantity of the organic and the suspended matter, respectively.

During the two three-hour runs samples for analysis were collected every ten minutes from the raw liquor, sedimented liquor, and final effluent, the small samples being mixt together to obtain an average sample for the run. In both cases the rate was maintained at 3.25 gallons per minute. The following data of the test were obtained:

DATA FROM TEST RUN OF FILTER

Test number.	Duration.	Loss of Head.		Quantity filtered.
		Initial.	Final.	
	Hours.	Inches.	Inches.	Gallons.
7	2.9	4	55	566
8	3.0	3	55	585

The chemical analyses for the two sets were very similar. The following table shows the mean values obtained:

ANALYSES OF RAW LIQUOR, SETTLED LIQUOR, AND EFFLUENT

	Parts per million.	Per cent. removed.
Raw liquor.		
Oxygen consumed:		
Total	9,400	. .
Dissolved	2,000	. .
Suspended	7,400	. .
Suspended solids	28,000	. .
Settled liquor.		
Oxygen consumed:		
Total	6,200	34
Dissolved	1,600	20
Suspended	4,600	38
Suspended solids	4,400	84
Effluent.		
Oxygen consumed:		
Total	2,200	77
Dissolved	1,700	15
Suspended	500	93
Suspended solids	575	98

The appearance of the effluent frequently changed materially during the run. Contrary to expectations and general experience, the best effluent was always obtained during the early part of the run. The very first portions of effluent were generally slightly turbid, after which a perfectly clear water came thru, as a rule, entirely free from suspended matter. This state of affairs continued until the loss of head had reached about 6 or 8 inches, when the effluent suddenly became turbid and continued so uniformly until the end. The inference was that under a tension or pull on the surface film represented by about 6 to 8 inches of head the finely divided matter contained in the liquor was pulled thru the surface and then thru the filter. It was thought that if this should be a correct interpretation of the phenomenon, it might be obviated in one of two ways—by increasing the toughness of the surface deposit, or by decreasing the size of the sand pores by use of a layer of finer material on the surface. Both of these methods were tried.

To increase the density and toughness of the surface film the surface was covered with liquor, the outlet being closed, and 2 ounces of sulfate of aluminum were added and stirred in. Fifteen minutes were allowed for the formation and settling of the precipitate, and the filter was then started. The following data were obtained.

DATA OF TEST RUN OF FILTER AFTER ADDITION OF ALUM

Duration of run	1.9	hours
Loss of head:		
Initial	14	inches
Final	55	inches
Quantity filtered	370	gallons

The chemical analyses resulted as follows:

ANALYSES OF RAW LIQUOR, OF SETTLED LIQUOR, AND OF EFFLUENT AFTER THE ADDITION OF ALUM

	Parts per million.	Per cent. removed.
Raw liquor.		
Oxygen consumed:		
Total	9,000	. .
Dissolved	1,600	. .
Suspended	7,400	. .
Suspended solids	27,300	. .
Settled liquor.		
Oxygen consumed:		
Total	6,000	33
Dissolved	1,600	6
Suspended	4,400	40
Suspended solids	4,500	84
Effluent.		
Oxygen consumed:		
Total	1,800	80
Dissolved	1,600	. .
Suspended	200	98
Suspended solids	450	98

The improvement of this effluent over that obtained without a coagulant is decided, but is hardly sufficient to warrant the extra cost of treatment. Previous studies had shown that it was necessary to add to the volume of waste on the surface of the filter at least 2 ounces of alum in order to bring about a satisfactory precipitation of the lime. Any less amount would not have produced a satisfactory precipitation in a short time. The total quantity filtered during the run was 370 gallons. This gives an amount of sulfate equal to a little over 2 grains per gallon for the entire run, or a consumption of 300 pounds of alum per million gallons. At a cost of 1 cent per pound (based on net w of sulfate of aluminum in the crude compound) this would amount to $3 per million gallons of waste, or 10 cents per ton of finished board. This additional cost for chemicals, together with the slightly additional expenditure for labor and water required by more frequent washing, would not seem to be justified in general by the slightly increased purity of the effluent. The results are given here and the cost estimated as a matter of record and in order to show what could be accomplished by the process if it were deemed desirable in any special case.

The second plan for preventing the small suspended particles in the liquor being drawn thru the surface was to use a surface layer of fine sand. A suitable grade of sand was obtained locally and screened thru a No. 20 screen. The sand thus prepared contained a considerable amount of rather fine material. Mechanical analysis showed that it had an effective size of 0.26 mm. and a uniformity coefficient of 2.0.

A 6-inch layer of the sand was placed on the top of the filter and washt. After washing, the surface was examined and found to consist of a well-mixt layer of coarse and fine material. Two runs were made with the filter as thus prepared. The following are the average data obtained:

Data of Test Run of Filter after Addition of Fine Sand

Duration of run	2.3 hours
Loss of head:	
Initial	6 inches
Final	55 inches
Quantity filtered	449 gallons

The appearance of these effluents was such that chemical analyses were not made. They were essentially like the others, and there was no advantage in the use of the layer of fine sand which could in any way offset the obvious disadvantage of the much shorter run.

The Sludge

Amount and Composition.—Thruout the experiments, except for the first few runs, the dirty wash water from the filter was run back into the sedimentation tanks. Eventually, therefore, all the material removed from the waste liquor was accumulated in the bottom of these tanks. At the conclusion of the experiments, which consisted altogether of 12 runs, dealing with a total of 4,900 gallons of the waste, the liquor was drawn off from the tanks as far as possible and the depth of accumulated sludge and remaining liquor was measured. The average depth was found to be 6 inches. After thoro mixing, a sample of the sludge was collected and allowed to stand in a glass cylinder for two hours. From a column of sludge 12 inches in depth a 2-inch layer of clear liquid separated at the top, leaving the depth of sludge on the bottom 10 inches. Therefore the 6 inches of sludge and liquor left in the tank was composed of 5 inches of sludge and 1 inch of water, so that 5 inches represents very closely the average depth of sludge in each tank and will be used in the calculations which follow.

Analysis of the sludge gave the following results:

ANALYSIS OF SLUDGE RESULTING FROM FILTRATION OF STRAWBOARD WASTE

Specific gravity	1.094	
Total solids	19.4	per cent.
Volatile	9.8	per cent.
Fixt	9.6	per cent.

From these data the following results are obtained:

Sludge in tank	78	gallons
Liquor treated	4,900	gallons
Per cent. of sludge (by volume)	1.6	

From 1,000,000 gallons of waste there will be obtained:

Sludge	79	cubic yards
Dry solids	28,000	pounds
Organic solids	14,100	pounds
Mineral solids	13,900	pounds

For each ton of strawboard there will be produced:

Sludge	4.7	cubic yards
Dry solids	1,680	pounds

A glance at Plate I, *B*, will indicate what these figures mean. The piles of straw there shown represent three months' supply for a mill producing 30 tons of board per day. Over one-third of the total weight of this straw will appear in the waste liquor.

Properties and Uses of the Sludge.—As is indicated by the analysis, the sludge is a thick mud. It is dark, muddy brown in color, and has the odor of straw. On exposure to the air it dries much more rapidly than would be expected, owing largely to the action of the air on the free lime. If allowed to dry in a mold, the resulting cast comes away clear and has taken a very clean impression of the mold. It is very brittle by itself. If, however, a little paper fiber be mixt with it before drying, the dry cast is fairly tough. Such a mixture could undoubtedly be used in many places as a cheap substitute for *papier-maché*.

The dry product had a specific gravity of 0.62. It will readily absorb considerably more than its own weight of water. Its porous nature suggests its use as a heat insulator, particularly in refrigerators.

This material possesses a certain value as a fertilizer. It contains a considerable proportion of calcium carbonate, a substance beneficial to cultivated land. It also contains 0.34 per cent. of phosphoric acid in an available form. Its loose, porous nature makes it particularly valuable for use on clay land, as such land is made much more porous by it and at the same time is sufficiently fine to retain the moisture well. This point was well brought out on examining one of the abandoned settling basins. This basin had originally been diked up about 6 feet above the surrounding fields, and had subsequently been completely filled with the sludge. On digging into this deposit, standing water was observed at a depth of less than 2 feet below the surface, altho the ground water level in the adjacent fields was at least 6 feet lower and the field had not been flooded for over a year.

Some experiments have been made with this solid residue as a base for the production of a sulfur dye. Fusion of the substance with twice its weight of a mixture of one part of sulfur and two of sodium sulfide yields a mass containing a considerable proportion, perhaps 20 per cent., of a brown sulfur dye. Purification of the resulting dye from the mass of inert material was not attempted, and further study is required to determine the most satisfactory procedure for the preparation and purification of this dye, but enough has been done to indicate that a low-grade sulfur dye can be made from this waste material. It dyes unmordanted cotton a good warm shade of brown, is fast to hot soap and to sunlight, and compares favorably in color and fastness with dyes on the market selling at 15 cents per pound.

Considerable attention has been given to the problem of finding profitable use for the residual organic matter which is the end product of the filtration processes here recommended. Altho the satisfactory solution of this problem would be highly desirable and would at once assure the treatment of all strawboard waste liquors, it must be remembered that this is merely a question incidental to the main problem. It is believed that the process of sedimentation, followed by mechanical filtration, essentially as described, furnishes by itself a solution of that problem which will prove of financial advantage to the manufacturers and of lasting benefit to all who have an interest in the purity of the streams below. It was therefore not deemed pertinent to the present investigation to pursue further the question of the utilization of the sludge. The suggestions here given, and particularly that in regard to the preparation of a dye, are merely intended to indicate the direction in which, according to the writer's views, future research would bring results of value.

Résumé of Method of Treatment

The following plan of treatment is recommended: The waste water from the beaters should be past thru a properly designed settling tank of such size that it will give a period of about one hour's storage. A tank built on the principle of the Dortmund tank would be preferable to any other, owing to its compactness and the possibility of continuous use. The tank should have a capacity of approximately 1,200 gallons for each ton of board produced per day by the mill.

The water should pass from the tank directly to the filters, which should be built in small units. The filters should have an available loss of head of at least 12 feet, and could be run at a rate of 100,000,000 gallons per acre per day. This would necessitate a filter area of approximately 16 square feet per ton of board produced daily. This figure allows 10 per cent. excess for repairs and washing.

The effluent should be pumped and used again for washing the filter and for beater wash water. It would at all times contain less impurity than does the very last water past from the beaters, and its use during the early part of the washing process could do no possible harm. To insure a proper washing out of the last of the lime from the stock, it would probably be found necessary to complete the washing with fresh water. In any case a saving of one-half to two-thirds of the amount of wash water now used could be realized, the amount of waste liquor being correspondingly reduced. The water used in washing the filter should be returned to the sedimentation tank, and would require no further treatment.

The sludge from the sedimentation tank could be most expeditiously dealt with by filter pressing. There would remain a fairly dry and hard press cake, which would require disposal unless some profitable use for it be found. Under the influence of the air and sun this material is speedily resolved into mineral matter, forming a sort of soil. It could be spread upon low land in thin layers and would then take care of itself.

Instead of being filter prest, the sludge might be discharged upon small areas of sandy soil where such are available or even upon somewhat larger areas of less porous soil, and allowed to dry out by draining and evaporation. The dry layer of sludge could then be removed and disposed of. No accumulation of the wet material should be allowed. When once dried out and subjected to the action of the sunlight and air it soon becomes harmless, but in deep beds and constantly covered with water it is subject to all the offensive putrefaction described in the case of the sedimentation fields. This process of spontaneous draining and drying out would probably be found the cheaper, but would require a considerable area of suitable land and would also involve more careful supervision. The amount of land required would depend wholly on the quality of the drainage. For average conditions it may be roughly estimated at 1,000 square feet per ton of board produced by the mill daily. The dried sludge would require removal before the application of more sludge.

Character of Waste Water after Treatment

The quality of the effluent from the proposed process is not all that could be desired. In spite of the fact that it is possible to remove over 90 per cent. of the suspended organic matter present in the liquor, the resulting effluent is still putrescible. That is, a bottle of the liquor shut up air-tight and kept at a warm temperature will in the course of a few days undergo putrefactive fermentation. The putrefaction is rather slow, however, and not offensive. In admixture with an equal volume of tap water the effluent does not putrefy even when inoculated with a small amount of sewage.

The fact that the effluent is practically free from gross suspended solids—that is, solids which will settle out on the bed of the stream—is of greater significance than the analytical data. As was pointed out in the earlier discussion of the problem (page 8), by far the greater part of the damage done to the polluted streams is brought about by the deposit of material in the stream beds. The effluent which has past the treatment here outlined will contain no material capable of settling out even in slack water.

The conclusion is therefore justified that the discharge of this effluent into a stream whose minimum flow equals in volume the flow from the mill would not produce a nuisance. With no allowance for a possible diminution of the amount of wash water, if used as suggested above, this means that the minimum stream flow must be at least 0.05 cubic foot per second per ton of board produced daily at the mill. A minimum flow of 0.1 cubic foot per second per daily ton would therefore provide for a generous factor of safety if the stream is reasonably unpolluted at the point of discharge.

The discharge of such an effluent into a stream highly polluted with sewage would probably be accompanied by an aggravation of the conditions already existing. There would, as usual, be a precipitation of the sewage material by the lime of the effluent. In all fairness it could be maintained that the organic matter of the effluent was not contributing to the nuisance. If, therefore, it should be decided that the addition of lime to a sewage polluted stream constitutes a nuisance, further treatment of the effluent would be required to remove this caustic lime. If, on the other hand, as would seem to be reasonable, it should appear that the real pollution of the stream lay in the sewage and the lime was incidental and was there by right, there would be no reason for such further treatment.

Cost of the Process

The cost of the process recommended cannot be discust in detail at this time. It would be largely the cost of installation. The design and construction of a suitable plant require expert attention, and the cost of the plant would depend somewhat on local conditions. The cost of maintenance would be slight. The cost of additional pumping to supply wash water say 5 per cent. more than the present amount pumped—can be determined readily. The services of one man, who could also assist in the mill part of the time, would be a sufficient addition for running the plant. The power necessary to pump the sludge thru the filter presses, if that plan were adopted, would not be noticeable in comparison with the total power used in the mill. If the sludge were disposed of by the other plan, evaporation and drying in the field, the services of another man would be required.

In conclusion, the following summary of the chief points of the present paper may be made:

SUMMARY

The present method employed for the treatment of strawboard waste liquor, that of sedimentation in large fields, is unsatisfactory and expensive and proceeds on a wrong principle.

The filtration of the liquor thru sand, so-called mechanical filtration, but without coagulants, after a short period of sedimentation will remove 93 per cent. of the suspended organic solids and 98 per cent. of the total suspended matter determined as turbidity.

Actual experiments have shown that the resulting effluent can be discharged into an equal volume of reasonably pure water without creating a nuisance. In particular, there will be no sedimentation of organic matter. If its discharge into a seriously polluted stream should bring about precipitation of sewage matter and consequent nuisance, the blame should in all equity be fixt on those contributing the sewage.

The sludge resulting from the sedimentation tanks, after pressing or spontaneous drying, is innocuous and makes good soil. It has some value as a fertilizer and is particularly valuable to mix with the clay soils of the Middle West to render them more porous. Other uses for this material are suggested, but they require further study.

The cost of the entire process is sufficiently low to admit of its adoption wherever stream pollution is serious.

[Reprinted from Technology Quarterly, Vol. XX, No. 2, June, 1907]

Contributions from the
Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

THE DETERMINATION OF THE ORGANIC NITROGEN IN SEWAGE BY THE KJELDAHL PROCESS

II. STUDIES ON DIRECT NESSLERIZATION

By LEYLAND WHIPPLE

The value of a method of analysis, when used in routine work, becomes to a considerable extent a function of the rapidity with which it may be carried out. In no case, perhaps, is this better exemplified than in the estimation of organic nitrogen by the Kjeldahl process, in sanitary water and sewage analysis. This determination, by far the most important, from the viewpoint of interpretation, involves one of the longest procedures, and is consequently not generally employed.

Several attempts have been made to shorten this process by nesslerizing the diluted digestate directly, without distillation. Unless special precautions are taken, however, certain constituents of the digestate are found to react with the Nessler's reagent, producing a turbidity in the presence of which it is not possible to make close comparisons of the color of the nesslerized tube with that of the standard. Of the heretofore published methods, only one, that of Kimberly and Roberts (1906), has been found to be uniformly successful under local conditions, and this method has in our hands failed to yield satisfactory results.

It is the purpose of this paper to present the results of some experiments carried out in this laboratory on direct reading of Kjeldahl digestates, and to give a procedure which has been found entirely successful here and which may be of application elsewhere.

Previous Results

Direct reading of diluted Kjeldahl digestates has been the subject of investigation both in this country and abroad. Rideal (1901) gives a procedure which consists in neutralizing with an excess of caustic soda, diluting to a definite volume, allowing to settle for a number of hours, and pipetting off a portion of the clear supernatant liquid for nesslerization.

Phelps (1904), at this laboratory, tried making up the digested sample to volume, taking out the requisite amount, neutralizing and making up to 50 c.c. in the Nessler tube. He found that in about half the cases a turbidity was produced on adding the Nessler reagent.

McGowan (1904) attempted to use a modification of the Rideal method by making *just neutral* with hydrate, and in some cases adding potassium oxalate to precipitate the calcium. He found, also, that in more than half the total number of determinations the tubes were too turbid to read. Furthermore, he pointed out a probable loss of ammonia by adsorption in the precipitate formed. He attributed the turbidity to the insufficient precipitation of the calcium.

As a result of an extended investigation carried out at the Columbus Sewage Testing Station, Kimberly and Roberts (1906) published a modification of the processes of Rideal and McGowan, which consisted in diluting the digestate to 100 c.c., nearly neutralizing with sodium hydrate, cooling, adding a slight excess of hydrate and then 2 c.c. of a 10 per cent. solution of sodium carbonate solution, diluting to a known volume, allowing to settle six hours, and nesslerizing a portion of the clear liquid. This method was the result of a series of investigations into the causes of turbidity, the latter being finally attributed to the presence of calcium and magnesium salts. Kimberly showed that an amount of calcium up to 2.5 mg. per nesslerized tube would not produce turbidity, but that in greater concentrations it would interfere with the process. He used a slight excess of caustic to precipitate the magnesium, and sodium carbonate to precipitate calcium. The long period of settling was necessary in order to remove the slow-forming calcium carbonate.

He states, further, that potassium permanganate cannot be used to complete the digestion, as the manganous sulphate formed will cause turbidity on nesslerizing. The cooling before final neutralization was recommended to avoid the escape of ammonium hydrate from the hot solution. He found it necessary, also, to purify the soda by permanganate, in order to remove iron and organic impurities. In his experiments on the accuracy of the process, he found that adsorption was a negligible factor. In numerous comparative determinations by distillation and direct nesslerization close agreements were obtained.

In an endeavor to obtain a method for the direct reading of Kjeldahl digestates at this laboratory, the method of Kimberly and Roberts was tried, but failed to yield satisfactory results, it being found impossible to obtain clear tubes upon nesslerization. We have therefore further investigated the causes tending to produce turbidity, and have succeeded in devising a modification of the Rideal method which is successful under conditions found here, and which should be applicable to all sewages except under conditions which will be defined later on in this paper.

CAUSES OF TURBIDITY IN THE TUBE

The causes of the turbid tube have been variously attributed to the presence of calcium, magnesium, sulphate ions, and manganous salts, resulting from the use of potassium permanganate to complete the digestion.

Kimberly and Roberts have shown that sulphate ions are not one of the disturbing causes. In regard to manganous salts, it is a well-known fact that permanganate is rapidly hydrolyzed and reduced in dilute solutions, either weakly acid or alkaline, and is then precipitated on standing. When used to complete the digestion, the permanganate is at once reduced by the hot acid, and settles out of the diluted digestate as a basic salt. Moreover, should traces of manganous sulphate yet remain in solution, they will be precipitated upon neutralization. Permanganate has been used throughout the present investigation and has never given rise to any cloudiness in the tube.

We have confirmed the conclusion of Kimberly and Roberts that calcium may be present in the tube up to 2.5 mg. without producing turbidity. As an amount of sewage is normally taken which will give a reading of not more than five on the colorimetric standards, corresponding to .05 mg. of nitrogen, it is clear that we cannot have more than fifty parts of calcium to one of nitrogen. That is, in a sewage in which the calcium content is not over fifty times that of the nitrogen, tubes which will give a reading of five or less may be nesslerized directly without any special precautions being taken to remove the calcium. Except in the case of a good sand-filter effluent from a sewage very high in calcium, this ratio will seldom be realized. Even in cases where this ratio is exceeded, it might be advisable to use a less amount of the sample, so as to make the reading about two on the standards. This would increase the allowable ratio of calcium to nitrogen to 125.

Similarly the allowable ratio of magnesium to nitrogen was determined, and found to be so low that the removal of magnesium appears to be an essential detail. An amount of magnesium in the tube of over .025 mg. will produce either a cloudiness or a considerable deepening of the color of the reagent. To determine the amount of excess hydrate required to effect sufficient precipitation of magnesium salts, a sample was made up containing about 0.12 mg. nitrogen as ammonium chloride, 2.5 mg. magnesium as chloride, and digested with 5 c.c. of sulphuric acid in the usual way, with the addition of permanganate. The digestate was diluted to 250 c.c., and successive portions of 10 c.c. each were neutralized with varying amounts of a 5 per cent. solution of sodium hydrate, starting with an amount just sufficient to neutralize the acid, as determined by a test portion, using phenolphthalein as an indicator. The samples were filtered through washed filters into Nessler tubes, and the filter and precipitate then washed with ammonia free water.

The results of this experiment are shown in the following table:

Tube.	5 per cent. hydrate. c c.	Reading.	Remark.	Corrected reading.*
1	7.2	. .	Very turbid	. .
2	7.5	. .	Very turbid	. .
3	8.0	About 5.0	Considerably turbid	4.8
4	9.0	5.0	Slightly turbid	4.8
5	10.0	4.8	Clear	4.6
6	12.0	4.9	Clear	4.7
7	15.0	5.0	Very slightly turbid	4.7
8	20.0	About 5.8	Considerably turbid	5.4

* A blank on 10 c.c. of the hydrate gave a reading of 0.2; the figures in this column have had this correction applied.

This indicates that after neutralization an excess of hydrate must be added equivalent to 1.5 grams per 100 c.c. of the diluted digestate, in order to effect a satisfactory removal of the magnesium. Furthermore, it is indicated, and we have further confirmed the fact, that the reading is not appreciably affected by an excess of hydrate unless in sufficient amount to itself cause turbidity. This amount has been found to be about 0.35 gram per 50 c.c. Nessler tube.

The addition of copper sulphate to hasten the digestion has no effect on the final result, as the copper is entirely removed by the hydrate.

It appears, therefore, that magnesium salts are one of the principal causes of turbid Nessler tubes; that the magnesium can be satisfactorily removed by an excess of sodium hydrate; and that this necessary excess is not in itself sufficient to produce turbidity.

METHOD

The detailed procedure which has been in use at this laboratory for the past three months is as follows:

Reagents.—The same as those used in ordinary Kjeldahl determinations of organic nitrogen, with the addition of a 5 per cent. solution of potassium or sodium hydrate.

Procedure.—Fifty c.c. of the sample (or a greater or less amount, according to the nitrogen content) are digested with 5 c.c. of concentrated sulphuric acid, nitrogen free, and a small amount of copper sulphate until colorless. The digestion is completed by the addition of a few small crystals of permanganate to the hot acid. After cooling, the digestate is diluted to 250 c.c., mixed, and a portion (say 25 c.c.) is pipetted out, mixed with an equal portion of 5 per cent. sodium hydrate solution, and filtered through a filter paper which has been washed previously with 100 c.c. or so of ammonia free water to remove traces of ammonia. Twenty c.c. of the filtrate are pipetted into a Nessler tube, made up to 50 c.c. with best water, mixed by pouring from one tube to another, nesslerized, and read after ten minutes. A blank should be run on the entire process, and the result subtracted from the reading.

DISCUSSION

This method has been in use in this laboratory for the past three months, and has given uniformly satisfactory results. In no case have we experienced any difficulty in getting a clear tube of the correct color to match the standards, even in tubes reading as high as seven or eight on the standards, corresponding to .07 and .08 mg. of nitrogen in the tube. In practice, however, readings of over five are discarded and new dilutions made, the rapidity of the process making it readily possible to introduce this desirable procedure.

In all these experiments, and in our regular work, the ordinary purified caustic soda in sticks has been used, preliminary purification having been found unnecessary.

ACCURACY

Duplicate determinations made on the same digestate by distillation and by the direct method show a very close agreement. The following analyses were made, on three different dates, on sewages and effluents of trickling filters:

TOTAL KJELDAHL NITROGEN
Parts per Million

Sample.	Distilled.	Direct.
Sewage	19.5	19.5
Sewage filtered	18.0	17.5
Sewage	20.0	19.5
Sewage filtered	18.0	18.0
Sewage	23.5	23.5
Sewage filtered	17.5	17.5
Effluent	15.0	15.0
Effluent filtered	9.5	9.0
Effluent	14.5	14.5
Effluent filtered	12.0	12.0
Effluent	13.5	Lost
Effluent filtered	12.5	12.5
Settled effluent	12.5	12.0
Settled effluent filtered	11.0	10.5
Settled effluent	12.0	11.5
Settled effluent filtered	11.5	11.0
Settled effluent	14.5	15.0
Settled effluent filtered	13.0	13.0

The uniformity of these figures shows the loss during filtration or by adsorption in the precipitate to be negligible.

This process commends itself for the following reasons:

(1) The great saving of time over the distillation process.

(2) The less bulky and bothersome apparatus required.

(3) An accuracy fully equal to that of the distillation method.

(4) The saving in time over all previously published direct methods, the immediate filtration taking the place of the long period of settling heretofore employed. The possible loss of ammonia in the filtration has been shown to be negligible.

(5) More satisfactory results locally than previously published direct methods, and greater probability of its being applicable under a wide range of conditions.

SUMMARY

(1) The direct nesslerization of Kjeldahl digestates is greatly to be desired, but unless special precautions are taken such a procedure will result in a precipitation of the Nessler's reagent by certain constituents of the digestate.

(2) The present study indicates that under ordinary conditions no trouble will be experienced on account of calcium, no special treatment for its removal being necessary unless the calcium content of the sewage is greater than fifty times the nitrogen content.

(3) Magnesium, on the other hand, even in small amounts, will cause a turbidity in the tube and render a correct reading impossible.

(4) Magnesium can be satisfactorily removed, but to do this requires an excess of sodium hydrate equivalent to a concentration of 1.5 grams per 100 c.c.

(5) The excess of sodium hydrate necessary to remove the magnesium is not great enough to interfere with the reading. In fact, this reading is not appreciably affected unless the concentration of hydrate is such as itself to produce turbidity, or about 0.35 gram per 50 c.c. Nessler tube.

(6) It is not at all certain that the turbid tube results solely from the presence of magnesium. It has been determined, however, that under the conditions required for the removal of magnesium any other deleterious constituent is also eliminated.

(7) A process is recommended whereby all disturbing constituents can be removed and the Kjeldahl digestate nesslerized directly. By filtering the neutralized digestate a saving of several hours can be effected over heretofore proposed methods.

REFERENCES

Kimberly and Roberts. Method for Direct Determination of Organic Nitrogen by Kjeldahl Process, Jour. Inf. Dis., 1906, 2, 109.

McGowan. Fourth Report Royal Commission on Sewage Disposal, 4, part 5, 35.

Phelps. A Critical Study of Current Methods for the Determination of Free and Albuminoid Ammonia in Sewage, Jour. Inf. Dis., 1904, 1, 327.

Rideal. Sewage, 2d ed., 1901.

2 plate
CS.

K
[illegible] 17 1910

not acc'd
F.J.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS

# CONTRIBUTIONS
FROM THE
SANITARY RESEARCH LABORATORY
AND
SEWAGE EXPERIMENT STATION

VOLUME V

REPRINTED PAPERS
PRICE, $1.00

BOSTON, MASSACHUSETTS
1909

(Massachusetts)

V II I

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# CONTRIBUTIONS
FROM THE
SANITARY RESEARCH LABORATORY
AND
SEWAGE EXPERIMENT STATION

VOLUME V

REPRINTED PAPERS
PRICE, $1.00

BOSTON, MASSACHUSETTS
1909

TABLE OF CONTENTS

Introduction. **William T. Sedgwick**, Director.

1. The Sewer Gas Question; with Special Reference to the Sanitary Significance of Bacteria in the Air of Drains and Sewers. C.-E. A. **Winslow**. [Report made to the Sanitary Committee of the National Association of Master Plumbers of the United States, and reprinted from the Report of the Sanitary Committee for 1907–08–09.]

2. The Disinfection of Sewage and Sewage Filter Effluents, with a chapter on the Putrescibility and Stability of Sewage Effluents. **Earle B. Phelps**. [United States Geological Survey, Water-Supply Paper 229 (Washington, 1909).]

3. The Pollution of Streams by Sulphite Pulp Waste. **Earle B. Phelps**. [United States Geological Survey, Water-Supply Paper 226 (Washington, 1909).]

4. Corrosion of Water Pipes. **Earle B. Phelps**. [Report made to the Sanitary Committee of the National Association of Master Plumbers of the United States, and reprinted from the Report of the Sanitary Committee for 1907–08–09.]

5. An Investigation of the Sanitary Condition of the Gowanus Canal, Brooklyn, N. Y. C. F. **Breitzke**. [*Technology Quarterly*, XXI, pages 243–280.]

INTRODUCTION

By W. T. SEDGWICK, Director

THE present volume is the fifth in a series of reprints of similar character, viz., of papers concerning various aspects of sanitary science, and connected more or less closely with public health problems arising from time to time in the regular work of a great modern school of science and technology. This volume, too, like those that have preceded it, owes its existence chiefly to the continued interest and the generous coöperation of an anonymous friend of the Institute, who, feeling keenly the incongruity of a twentieth century civilization which boasts of its achievements in mechanical, industrial, and chemical science and yet values human life so meanly as to go on polluting rivers and harbors with vast and ever increasing streams of putrefying sewage, is anxious to bring about a change for the better. Happily, signs are not wanting that many others, also, are today beginning to be conscious of the same incongruity, for the previous volumes of this series are already long since out of print, owing to an eager demand for them which has been as gratifying as it was unexpected.

Reforms, of whatever sort, are seldom without their drawbacks, and experience is showing that the water-carriage system of sewerage, while on the whole, for the use of thickly settled communities, an immense improvement upon all previous systems, brings with it certain serious disadvantages. Of these one is that, by enormously diluting with water the dangerous wastes of human and animal life, it vastly increases volume, and for this reason, and also because water is an excellent solvent as well as extremely penetrating, the mixture mingles readily with most materials so that wide dispersion of the wastes in the environment is favored and facilitated. Another disadvantage of the water-carriage system is that on sufficient dilution the objectionable and characteristic appearances and odors, which serve as useful warnings of the presence of these dangerous wastes, diminish or even disappear, although such diminution or disappearance does not generally mean that they are destroyed, but perhaps only more widely separated or dispersed. Still another disadvantage is that the water-carriage system removes rapidly and often to a considerable distance the fluid filth of a community, so that, while accomplishing quite perfectly a most desirable riddance, the very perfection of the system puts the sewage out of sight and out of smell, and hence too often out of mind, of those responsible alike for its production and for its ultimate sanitary disposal. As a corollary of these consequences of modern systems of sewerage, local nuisances, and dangers formerly domestic and almost intolerable have, indeed, been removed to a distance, or even done away, but often only at the cost of their conversion into more widespread, though often invisible, dangers. The most hopeful sign of progress in the subject of sewerage and sewage disposal is the growing sensitiveness of the public to this fact, for it is obviously bad citizenship for any one to clean up at the expense of others, and no more so for an individual or a family than for a community of individuals or families. The pouring of fluid filth into our rivers, lakes, and harbors does, of course, rid our cities, towns, and villages of that filth, and in so far it is commendable. But if by this act we simply move that filth to a distance, there to make for ourselves or for others more or less of the same trouble which it formerly made for us, then we are hardly superior in sanitation to those half-nomads who encamp on one spot until they have made sanitary conditions intolerable, and then remove their abode to a fresh location.

Most of the papers in this volume deal with various aspects of the endeavor—now almost world-wide—to purify that fluid filth which we call sewage, so that it shall not merely be turned as it comes into streams, lakes, or the sea, there to cause pollution, putrefaction, or possibly disease, but shall first be worked over in some way and made unobjectionable to the eye and the nose, and innocuous to life and health.

Professor Phelps's paper on the pollution of streams by the wastes of mills making wood-pulp by the sulphite process is a courageous attempt to grapple with a very difficult and growing problem, while another paper from his pen, on the disinfection of sewage, is a valuable continuation of his earlier and epoch-making work on that timely and interesting subject. If by disinfection of sewage or water the danger of their transportation of specific disease germs can be eliminated, and if by any process whatsoever the danger of putrefaction, present and future, can be overcome, then, as will follow from what has been said above, the objectionable and dangerous features of the fluid filth of communities will largely disappear.

The paper by Professor Winslow on the sanitary significance of bacteria in the air of sewers and other drains is noteworthy for two reasons. First, because it serves to establish by the only certain method known to science—the method of experiment—a harmony such as ought to exist always between the results of experiment and the results of experience. This paper deals, as its title hardly suggests, with the long popular theory of sewer gas and its dangers—a theory which, after having enjoyed an immense vogue, rapidly declined in importance during and after the decade of the great pathological discoveries (1876-86) and the establishment of the parasitic theory of infectious disease. Recently, however, it has been revived and strengthened by experimental evidence obtained by a distinguished English investigator. It therefore became imperative to reëxamine it and to confirm if possible the new evidence. This task Professor Winslow has patiently and skillfully undertaken, with the results stated in his paper.

In the second place, this piece of work deserves special attention because it was carried out largely by funds contributed for the purpose by a committee—the Sanitary Committee—of the Master Plumbers' Association of the United States. This committee, of which Mr. David Craig, a practical plumber of Boston, was chairman, desired to do something by scientific research to increase the knowledge available for the practical purposes of the plumbing trade. The chairman accordingly applied to the director of the Sanitary Research Laboratories and Sewage Experiment Station for advice concerning the status of the sewer gas problem and its real importance. He was eventually referred to Professor Winslow as one competent to give further advice and to make all necessary investigations, and the paper here reprinted is the practical outcome of Mr. Craig's and Professor Winslow's plan of attack. It is impossible not to admire the wisdom, the liberality, and the public spirit of the leaders of a modern trade which thus, like the guilds of the Middle Ages, seeks earnestly, intelligently, and scientifically to make more secure those principles which shall serve as safe guides in practice.

The Staff of the Laboratory and Station remains, happily, almost unchanged, so that a continuous plan of work has been followed out from the beginning. The principal workers and designers of work have been, as hitherto, Professor C.-E. A. Winslow, Biologist in Charge, and Professor Earle B. Phelps, Research Chemist and Bacteriologist.

It is, however, to the anonymous Donor, whose keen and stimulating suggestions and criticisms and whose substantial support have given both life and power to the work, that public thanks are primarily due for the results attained.

The Sanitary Significance of Bacteria in the Air of Drains and Sewers

Charles Edward Amory
By C.-E. A. WINSLOW

Biologist-in-charge of the Sanitary Research Laboratory and Sewage Experiment Station of The Massachusetts Institute of Technology

REPORT MADE TO THE SANITARY COMMITTEE OF THE NATIONAL ASSOCIATION OF MASTER PLUMBERS OF THE UNITED STATES, AND REPRINTED FROM THE REPORT OF THE SANITARY COMMITTEE FOR 1907-1908-1909

BOSTON, MASS, 1909

THE SANITARY SIGNIFICANCE OF BACTERIA IN THE AIR OF DRAINS AND SEWERS.

C.-E. A. WINSLOW
Biologist-in-charge of the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology

Contents.

I. History and Present Status of the Problem.
II. Recent Experimental Results.
III. Repetition of Horrocks' Experiments.
IV. Observations on the Velocity of Air Currents Necessary to Transport Bacteria.
V. Preliminary Tests of Quantitative Methods for Enumerating Bacteria in Air.
VI. Enumeration of Bacteria in Air over Foaming Liquids.
VII. Enumeration of Bacteria in Plumbing Pipes over Foaming and Splashing Liquids.
VIII. Sewage Bacteria in the Air of Plumbing Pipes under Natural Conditions.
IX. Conclusions as to the Role of Sewer and Drain Air in the Spread of Bacterial Infections.

I. HISTORY AND PRESENT STATUS OF THE PROBLEM.

In 1858, when the causes of epidemic disease were still shrouded in profound mystery, an able and distinguished sanitarian, Charles Murchison, brought forward what he held to be conclusive evidence that typhoid fever was "produced by emanations from decaying organic matter." To disease thus generated spontaneously from decomposing filth he gave the name "pythogenic" from two Greek words meaning "generated by decay." For a long time this theory of disease held complete sway, particularly in England. It was energetically applied by Chadwick and others to the practical reform of existing conditions and produced a far-reaching improvement in the cleanliness of cities and towns, not only in England, but in every other civilized country. In particular the substitution of house drainage and municipal sewerage systems for privy vaults and cesspools made rapid progress to the notable advancement of the public health.

It was not unnatural that the horror of filth inculcated by these early sanitarians should have developed into an equally extreme dread of the systems of pipes and drains by which the filth was carried away. Sewer gas became the residuary legatee of the whole pythogenic theory. Even twenty-five years ago it was conceived as a deadly miasma laden with the elements of almost every disease known to medical science. One prominent writer of the time said, "If we look for the cause of the large mortality from zymotic diseases in our cities, we find it principally in sewer-gas poisoning. Other causes operate to swell the total, but to bad plumbing we may attribute the prevalence of pythogenic pneumonia, peritonitis, inflammatory rheumatism, typhoid and malarial fevers, croup, diphtheria, and many kindred diseases." This is scarcely an extreme statement of the best sanitary opinion of a generation ago.

When the germ theory of disease was established between 1860 and 1880, by the work of Pasteur and Koch, it was necessary to revise these earlier views. It was proved by Pasteur and his successors that epidemic diseases are caused not by gaseous emanations but by minute plant and animal parasites and that these parasites are not generated in decomposing filth but come from previous cases of disease. It was easy to see how filthy conditions, which lead to the contamination of food by excreta, promote the spread of germs. It did not follow, however that the air of drains and sewers could spread the living microbes of disease, without the direct contact of some more tangible carrying agent. This point remained to be proved; and a new field of experimental bacteriology had to be developed before the question could be answered. Nägeli was, perhaps, the first to study this point carefully. In his book *Die niederen Pilze,* (Munich, 1877), he reported numerous experiments bearing on the transmission of germs from liquids into the adjacent air. Putrescent and putrescible liquids were kept in sealed vessels together for over three years without air infection taking place; in another series of experiments air was drawn through a layer of sand, wetted with a putrescing liquid, and then through a sterile infusion, without infecting the latter. Nägeli concluded that "Infectious materials in general, pass into the air only after drying, and then in the form of dust."

If this conclusion were justified there seemed little danger of the carriage of bacteria by the constantly saturated air of sewers. A new possibility was suggested at about this time, however, by some experiments of Sir Edward Frankland in England on the discharge of chemicals in solution into the air under various conditions. He used a solution of lithium chlorid and tested for its presence by exposing the air above to the action of a Bunsen burner. After violent agitation with a wooden rod no lithium could be detected in the air. When, on the other hand, effervescence was produced in the solution by the addition of hydrochloric acid and marble, the characteristic color of lithium was apparent in the Bunsen flame at the end of a tube 21 feet above the liquid. The conclusions were drawn that "the moderate agitation of a liquid does not cause the suspension of liquid particles capable of transport by the circumambient air," but "the breaking of minute gas bubbles on the surface of a liquid consequent upon the generation of gas within the body of the liquid is a potent cause of the suspension of transportable liquid particles in the surrounding air; and therefore when, through the stagnation of sewage or constructive defects which allow of the retention of excrementitious matters for several days in the sewer, putrefaction sets in and causes the generation of gases, the suspension of zymotic matters in the air of the sewer is extremely likely to occur." (E. Frankland, On the Transport of Solid and Liquid Particles in Sewer Gases; Proceedings of the Royal Society of London, 1876—7, XXV., 542.)

Almost exactly similar results, as regards bacteria, were reported in this country by Raphael Pumpelly in a communication to the National Board of Health on The Relation of Soils to Health, (Annual Report of the National Board of Health for 1881, p. 223). He drew air over a decomposing liquid and then bubbled it through a sterile putrescible fluid; or else bubbled it through the two liquids in succession. His final conclusions were as follows: "At normal summer temperatures no germs were given off from the decomposing liquids whenever their surfaces remained unbroken, even though in some of the experiments the air was continuously conducted over them in a slow current. When the surfaces of the liquids were broken, however, by the bursting of bubbles, germs were invariably given off and the sterilized infusions infected, no matter how slowly the aspiration was conducted."

These investigations clearly indicated that bacteria could be given off to the air from an infected liquid by the bursting of bubbles. It was important to determine by an examination of the actual conditions in drains and sewers how serious this contamination might be; and in the eighties, when bacteriology was a fascinating novelty, there were many investigators ready to attempt the task.

Some of the earliest bacterial examinations of sewer air were made by the French bacteriologist, Miquel, and reported in his work on the living organisms of the air, (P. Miquel, Les organismes vivants de l'atmosphere, Paris, 1883). He discussed his results as follows: "In summer the air of the Rue de Rivoli may be five or six times as impure as the air of the sewer. In winter the reverse relation may be found; the air of the public street may be five or six times as pure as the air of the sewer below." Miquel found that the germs isolated from sewer air were of somewhat different character from those observed in the atmosphere of the street. They grew more rapidly in his flasks, more frequently produced putrefactive changes and more often grew under anaerobic conditions. Inoculation into animals, however, failed to reveal the presence of any pathogenic forms.

At a later date, in 1893, Miquel began to make routine monthly examinations of the air of the Paris sewers in connection with the work of the Montsouris observatory. From that year until 1899 he published annually a table, showing, by months, the relative number of bacteria in the air of a Paris street, (Hotel de Ville), and in the Paris sewers, in comparison with the number present in the air of the country at Montsouris, (Annuaire statistique de la ville de Paris). The yearly averages for the three locations are shown in the table below.

BACTERIA IN COUNTRY AIR, CITY AIR AND SEWER AIR

(Miquel). Bacteria per cubic meter.

Year	Country Air Montsouris	City Street Hotel de Ville	Sewer Air
1893	285	8435	5015
1894	230	9775	2920
1895	330	7615	2590
1896	—	6205	3965
1897	197	5410	3875
1898	—	5200	2075
1899	—	6595	2910

Uffelmann in 1886-7, (Uffelmann, Luftuntersuchungen, ausgeführt im hygienischen Institut der Universität Rostock, Archiv fur Hygiene, 1888, VIII., 262), examined the air of the main drain of a house at Rostock just above what corresponded to the running trap, taking 9 samples at intervals extending over a year. The largest number of bacteria found in 10 liters of air was 8, the smallest 0, and the average, 3. *Aurococcus aureus,* (*Staphylococcus pyogenes aureus*), was isolated twice, but no other pathogenic organisms were found.

In 1887, Petri examined the air of a Berlin sewer and found on one occasion 1 bacterium and 3 molds in 100 liters of air; on another occasion no bacteria and one mold in the same volume, (R. J. Petri, Eine neue Methode Bacterien und Pilzsporen in der Luft nachzuweisen und zu zählen, Zeitschrift fur Hygiene, 1888, III., 1).

One of the most important studies of the actual condition of sewer air was carried out in England in this same year (1887) by Carnelley and Haldane (T. Carnelley and J. S. Haldane. The Air of Sewers, Proceedings of the Royal Society of London, 1887, XLII., 394 and 501). These investigators examined the sewers under the Houses of Parliament at Westminster, and also a number of sewers in Dundee, using Hesse's sedimentation tube method for their quantitative work. In each case their results were controlled by the examination of the air of adjacent streets. It appeared that in almost every case the number of micro-organisms present was smaller in the sewers than in the streets. The average for the whole series gave about 9 per liter in the former and 16 per liter in the latter. Furthermore the number of micro-organisms present was highest in the best ventilated sewers and varied with variations in the contents of the street air. The kinds of colonies appearing on the plates and the proportion of molds to bacteria was the same in street and sewer air. The authors concluded that "The micro-organisms in sewer air come entirely, or nearly so, from the outside and are not derived, or only in relatively small numbers, from the sewer itself." They note, however, one interesting exception. In several cases drains entering the sewers from above discharged their contents so as to produce a violent splashing. Under such circumstances a considerable increase in the bacterial content of the air was apparent in the vicinity.

The points of greatest significance in this work appear to be two; first, that air in contact with a stream of quietly flowing, infected liquid contains less bacteria, rather than more, on account of the proximity of the wet surface; and second, that the splashing of such a liquid may cause at least a transitory infection of the adjacent air. Both these facts were also demonstrated by Carnelley and Haldane experimentally in the laboratory. They drew the air of the room through a glass tube 5 feet long, in which a stream of water was flowing,—the velocity of the air current being 10 inches per second. The number of bacteria in the air decreased by nearly half. On the other hand air drawn through a box into which an infected liquid was splashed from a height showed an infection of 300—600 bacteria per liter even after passage through the 5-foot glass tube.

The final conclusions of the authors were as follows, "The results of the foregoing investigations are clearly such as to make us much more suspicious as to supposed evidence of the bad effects of ordinary sewer air, such as that of the sewers examined by us. At any rate it is evident that 'sewer gas,' unless it has been vitiated by splashing, has a much less deadly composition than is often supposed."

Essentially the same experiments were presented by Dr. Haldane at the Bolton Congress of the Sanitary Institute. (J. S. Haldane, The Air of Buildings and Sewers; Transactions of the Sanitary Institute of Great Britain, 1887-8, IX., 395); but he also reported some additional examinations made in the sewers of Bristol which were selected from the fact that they were entirely closed except at two manholes near the outfall. At one manhole in which a current of air was setting out from the sewer only 2 micro-organisms per liter were found. At the other manhole there was a down current which mixed street and sewer air. The number of organisms here was about 8 per liter against 13 for the air of the street.

Similar results were reported a little later by Robertson, (A Study of the Micro-organisms in Air, especially those in Sewer Air, and a New Method of Demonstrating them; British Medical Journal, 1888, Dec. 15). He found less bacteria in the air of the sewers of Penrith, than in street air; the average numbers per liter were 4 and 6 respectively. More bacilli were found in the sewer air and more cocci in the street air.

A few years later, two important reports upon this subject were made to the London County Council by Laws, (J. P. Laws, Report on Sewer Air Investigations, London County Council No. 126, 1893), and J. P. Laws and F. W. Andrewes, Report on the Result of Investigations on the Micro-Organisms of Sewage. London Council No. 216, 1894). In the first of these papers Mr. Laws reported from an examination of London sewers that, "Sewer air contains a smaller number of bacteria than outside air," and that, "the micro-organisms in the sewer air are related to the micro-organisms in the air outside, and not to the micro-organisms of the sewage." From a series of experiments carried out in an experimental 9 foot sewer, 80 feet long, he concluded that the wetted surfaces of a sewer cannot give off germs to the air under natural conditions. He kept the sewer full for several periods of 24 hours, partially emptied it, and drew air through it, even at rates as high as 5 and 15 feet per second, without finding evidence that bacteria had been detached from the walls. Even splashing he concluded was unlikely to produce appreciable infection. Sewage falling into an egg-shaped sewer, 11 feet by 9, from the middle of its height produced practically no effect upon the number of micro-organisms in the air.

In a second investigation, in collaboration with Dr. Andrewes, Mr. Laws extended his work by a careful comparison of the kinds of bacteria found in sewage and sewer air. The most abundant forms in the sewer air were molds and micrococci, which are characteristic of ordinary street air and are rare in sewage. On the other hand, *B. coli* the most typical sewage form, was never found in sewer air. The authors conclude as follows, "We consider, therefore, that the study of the sewage bacteria, on which we have been engaged, fully confirms the conclusion previously arrived at from the study of the micro-organisms of sewer air, viz., that there is no relationship between the organisms of sewer air and sewage."

At about the same time Smith, (J. McG. Smith, Air in the Sewers of Sydney, Sixth Annual Report of the Metropolitan Board of Water Supply and Sewerage, 1893), reported rather high numbers of bacteria in the air of the sewers of Sydney. As an average of 20 determinations he found 225 germs per liter, the individual numbers ranging from 7 to 2260. The particular forms listed by him were almost without exception organisms common in street air.

A year later, in 1894, Dr. A. C. Abbott of Philadelphia reported an interesting series of experimental studies along the line of the earlier work of Nägeli and Pumpelly. (Chemical Physical and Bacteriological Studies upon Air over Decomposing Substances with special reference to their Application to the Air of Sewers; Transactions of the Congress of American Physicians and Surgeons, Third Triennial Session, p. 28). When air was bubbled through an infected liquid and then drawn through a tube of 15 mm. inside diameter and 1 meter long bacteria were transported by a current, having a velocity of 16.5 cm. per minute, but not by a current of 8.6 cm. per minute or less. With a tube 4.5 meters long a velocity of 268 cm. per minute carried bacteria in only two out of four experiments. In a second series of investigations Petri dishes were exposed in a large bell jar around an open dish of a culture of *B. prodigiosus*. Bubbling of the culture was brought about, either by adding to it a solution of dextrose and a culture of yeast, or by blowing air into it through a tube passed through the side of the bell jar. When the culture was agitated by natural fermentation no colonies of *B. prodigiosus* appeared on seven plates after three days. With artificial bubbling at a low velocity, (3 1-2 liters in 6 hours), 12-38 colonies appeared on the plates after twelve hours. Dr. Abbott concluded that the danger of bacteria being transmitted under natural conditions was practically negligible.

There was an important discussion of the sewer gas problem at the meeting of the German Society of Public Health at Stuttgart in 1895. Dr. Kirchner of Hanover, and City Engineer Lindley of Frankfurt presented the chief paper of the session, (M. Kirchner and Lindley, Schädlichkeit der Canalgase und Sicherung unserer Wohnräume gegen dieselben, Deutsche Vierteljahrsschrift fur offentliche Gesundheitspflege, 1896, XXVIII., 152). No new experimental data were offered but the evidence at hand, bacteriological and epidemiological, was reviewed, and the following principal conclusions were reached:

1. The assumption of the spread of epidemic diseases, such as Typhoid, Cholera and Diphtheria, by sewer gas does not harmonize with our present knowledge of the nature of the causative agents of these diseases.

2. On the other hand, the gaseous products of decomposition arising in sewers and house-drains may be harmful, indirectly if not directly, to those exposed to them for a considerable time; they may produce nausea and may lower the general tone of the body, including its resistance against disease." In the succeeding discussion which was participated in by a number of the leading sanitarians of Germany, similar opinions were expressed by many, although the conclusions of the authors which were presented in the form of resolutions, were not adopted by the Congress. In the discussion of Kirchner and Lindley's paper, (Deutsche Vierteljahrsschrift fur offentliche Gesundheitspflege, 1896, XXVIII., 196), Ficker stated that in experiments made at the Hygienic Institute of Breslau it appeared that air currents of a velocity of several meters per second would not lift specific germs from half-moist soil or from various surfaces on which they had been dried. On the other hand, the same observer found that when an infected liquid was discharged in a fine spray into a tube, an air current of .5 cm. per second could transport germs to a vertical distance of seven meters.

No further experimental results on the bacteriology of sewer air appear to have been reported, from 1896 to 1907. Public opinion among hygienists molded itself upon the data accumulated in the eighties and early nineties. The interpretation placed upon these data has, however, varied curiously in different countries, and has given rise to that anomalous, but not unprecedented phenomenon, a national difference in scientific opinion.

In Germany the obvious practical difficulty in conceiving of the transfer of infectious germs by the agency of moist air, and the experimental results of Nägeli, Miquel, Petri, Uffelmann, Carnelley and Haldane and Laws and Andrewes, have led to an almost universal scepticism

Prof. Flügge of Breslau, as far back as 1889, (Grundriss der Hygiene), said, "Still less are the gaseous products of fecal decomposition in position to carry infection. The special danger from fecal matter has been erroneously held to lie in these emanations. Malodorous gases from closets or sewers have been held responsible by physicians and laymen alike, particularly in England, for the spread of typhoid, diphtheria, erysipelas, puerperal fever, etc.; but this attitude is entirely uncritical and ignores the most recent results of investigation. The untenability of such views has been clearly shown above." In one of the most important German treatises on hygiene, Büsing (Die Kanalisation Weyl's Handbuch der Hygiene, Band II), says, "Whether besides the poisonous gases in sewer air, the micro-organisms present have any appreciable significance, is doubtful. Miquel has made studies of the occurrence of bacteria in the air of some Paris sewers with good currents which showed that their number was small, smaller than the number found in the air of hospitals, and much smaller than the number found in the air of streets in which there was considerable traffic."

These quotations are typical of German expert opinion in regard to the transmission of bacteria by sewer air; and in this country the best sanitary authorities have reached identical conclusions.

Dr. Charles Harrington, perhaps the leading medical sanitarian in this country, said, "The majority and the best of German investigators, as Flügge, Rubner, Gärtner, Soyka, Prausnitz and others, maintain that sewer air and sewer gases are quite incapable of conveying the germs of typhoid fever and other infective diseases. It is true that some of the gases given off in the putrefaction processes which go in sewers are more or less poisonous, but whether they are capable of producing any injurious effects depends very much on the amount inhaled and on the degree of concentration. In any event, they are certainly incapable of producing any infective disease in the absence of the specific germ," (C. Harrington, A Manual of Practical Hygiene, Philadelphia and New York, 1901).

In the engineering branch of the profession the same opinion prevails. Considerable attention has been directed to the question during recent years in the city of Winnipeg, Manitoba, on account of an undue prevalence of typhoid fever. This was attributed in public discussion to the foul air arising from sewer inlets and ventilating manholes. After a careful study by Col. H. N. Ruttan, the City Engineer, and by Allen Hazen, Consulting Engineer, of New York, Mr. Hazen reported that Col. Ruttan has "investigated the plumbing in a considerable series of houses in Winnipeg with the general result of finding that the plumbing is not associated with typhoid fever. In fact, his statistics show a somewhat larger proportion of cases of typhoid fever in the houses where the plumbing is good, than in those where it is defective." Mr. Hazen sums up the best current American opinion in the following sentence: "After many years of experience and long-continued investigation there is not the slightest reason to believe that infectious diseases are carried by the air of sewers," (Engineering News, LIII., 246). So Whipple, in the latest American text-book on typhoid fever, (G. C. Whipple, Typhoid Fever, New York, 1908), says, "Typhoid germs do not readily leave a moist surface. Sticky by nature, they adhere until dessication loosens their dead cells. For this reason, sewer air is not to be looked upon as a direct means of infection."

In England, on the other hand, a widely different attitude toward the sewer gas question has been maintained. The old pythogenic theory has kept a strong hold on the minds of the conservative British sanitarian; and the numerous cases where typhoid fever and other diseases have been attributed to sewer gas by attending physicians and health officers have outweighed scientific experimental evidence.

In Notter and Firth's Standard Hygiene the authors say of sewer air, "Fungi and bacteria grow rapidly in such air, and meat and milk soon taint when exposed to it. We must also suppose, for facts leave us no other explanation, that those agencies which produce enteric fever may also be present. That dysentery and diarrhoea may also be caused by exhalations proceeding from a foul sewer we cannot doubt but the precise agency is here also unknown. Diphtheria and acute follicular tonsilitis are also associated with sewer air; and, if the disease does not originate *de novo,* when once it breaks out, its tendency is to spread where the air and soil are polluted by sewage," (J. L. Notter and W. H. Horrocks, The Theory and Practice of Hygiene, London, 1900).

To quote an engineer, Maguire, in his lectures on Domestic Sanitary Drainage and Plumbing, (London, 1901), says, "It is almost a settled question that the germs of typhoid fever, cholera, dysentery, diarrhoea and other diseases may be present in and spread by cesspool and sewer air. Small-pox, scarlatina, measles, etc., if not arising directly from sewer air, may be communicated from house to house by unsuspected sewer and drain connections of one or more houses with an infected house on the same line of public sewer." Middleton, writing from the standpoint of the architect (The Drainage of Town and Country Houses, London, 1903), states that the "principal disadvantage," of the water-carriage system of sewage "lies in the possible generation of sewer gas, and the possibility of the communication of disease germs from house to house."

Much less extreme views have been expressed by other English sanitarians, of the highest standing. Not to quote Carnelley and Haldane and Laws and Andrewes further, reference may be made to H. A. Roechling who in his admirable book on Sewer Gas and its Influence upon Health, (London, 1898) sums up as follows, after some initial hesitancy, "looking at the whole case and making all due allowances, it appears to the author that the chances of typhoid fever being brought about through the conveyance of the *Bacillus typhosus* in sewer air are somewhat remote."

Other authorities in England have been inclined to suspend judgment on the whole matter. Thus in the "Surveyor" for April 17, 1908, is the following editorial comment:

"As regards the bacteriological aspect of the question, there is so much difference in the results obtained from the experiments of the most eminent men that one can only look on and wonder. When one reads that, from the experiments of Mr. J. Parry-Laws and Dr. Andrewes on the micro-organisms of sewage and sewer air, it has been found that 'sewer air has no power of taking up the bacteria from the sewage with which it is in contact, and that, bacteriologically, the air of sewers is no worse than that of the street above, and that, in fact, the number of micro-organisms found may actually be less, while the types of germs are precisely those present in the external air, and not those of sewage; that, in fact, the *B. coli communis* is never found in sewer air, although it is present in such enormous numbers in sewage, and that the possibility of the existence of the typhoid bacillus in the air of sewers is infinitely remote! When one reads statements such as these and then compares them with the statements made by other eminent sanitarians, scientists and bacteriologists who are in opposition, it is difficult to arrive at any conclusion. With Mr. Read, we ask for 'a series of continuous experiments upon an actual drainage and sewage system,' lasting over a considerable period. Until then, argument is little better than beating the wind."

To sum up: the experiments carried out prior to 1896 showed that bacteria might be transferred from sewage to the air above,—but apparently only by active splashing or bubbling. The actual number of bacteria present in the air of sewers and drains was so small as to suggest that infection of this sort was inappreciable in amount. These experiments have convinced the sanitary authorities of Germany and the United States that the danger of transmitting disease germs in sewer air is negligible. In England, on the other hand, a strong body of sanitarians still maintains the reality of the danger.

II. RECENT EXPERIMENTAL RESULTS.

A little over a year ago, at the request of the National Association of Master-Plumbers, I attempted to gain some new experimental evidence as to the practical probability of the carriage of bacteria in sewer and drain air. The experiments of ten years before had not carried universal conviction, even in regard to the air of sewers; they threw still less light upon the conditions which exist in house drains themselves. It seemed therefore important to accumulate further data by actual observation.

My experiments were carried out with an experimental stack of four-inch soil pipe, 15 feet in height, connected at the bottom with an open running trap, and at the top with an exhaust fan.

Sewage could be discharged into the pipe by a branch connection entering two and a half feet above the running trap. Air was drawn up the pipe at high speeds by the exhaust fan, and immediately after stopping the fan, samples of air were collected from stop cocks at intervals along the stack.

Four conditions were studied. In one series of experiments the running trap was entirely sealed by pouring in 2 liters of sewage. Only the maximum draft of the fan, amounting to a flow of 790 feet per minute through the open pipe, could unseal the trap under these conditions. In one of two tests a slight increase in the number of bacteria was noted at the stop cock 2 feet above the trap after drawing the air through the sewage in this way. In a second series of experiments the running trap was partially sealed by pouring in a liter and a half of sewage. When air was drawn through this seal at a rate corresponding to 490 feet per minute, one or two germs per liter only appeared in the pipe, about the number found in normal air. With a rate of 620 feet on the other hand, 18 bacteria per liter appeared in one test 2 feet above the trap; 14, 7 feet above; and 5, 12 feet above. In another test characteristic intestinal bacteria appeared two feet above and 17 feet above the trap at the 620 rate. When air was drawn at high velocities over a liter of sewage in the bottom of the unsealed trap, no perceptible increase was noted in the bacterial content of the pipe. Finally, in a fourth series of tests, the lower two and a half feet of the stack were thoroughly wetted by allowing sewage to flow in through the side connection. Air drawn over this wetted surface showed in one case, with an air current of 790 feet per minute, a slight increase in the number of bacteria present, (5 per liter, 12 feet above). As a general result of these experiments I concluded that very strong currents of air could detach bacteria from sewage through which they bubbled or from moist surfaces over which they passed, so as to cause an appreciable increase in the bacterial content of the air. More moderate currents, such as would occur under actual conditions apparently failed to do so. Furthermore, even under the most extreme conditions the increase in the bacterial content of the drain air was small. Only three specific intestinal organisms were found in the air in my entire series of experiments. I concluded that "with such a high dilution the chance of infection through the drain air was but slight," and that "the carriage of disease germs from the air of a house drainage system is an improbable contingency."

At just about the time at which I made this report to the National Association of Master Plumbers another series of experiments of great importance was reported by an English bacteriologist, Major W. H. Horrocks of the Royal Army Medical Corps of Great Britain. This communication was entitled, "Experiments made to determine the conditions under which 'Specific' Bacteria derived from Sewage may be present in the Air of Ventilating Pipes, Drains, Inspection Chambers and Sewers." It was read before the Royal Society, February 7, 1907, and published in the Proceedings of the Royal Society, Series B, Vol. LXXIX., No. B 531, p. 255.

Major Horrocks approached the subject from the general standpoint of the English sanitarians, with the assumption that the carriage of bacteria by sewer and drain air was a probability at least. He stated his general object as follows: "Most sanitarians at the present time believe that when sewage is in a putrefactive condition and gas bubbles rising through it are bursting at the surface, bacteria may be carried into the air of drains and sewers. It is also considered possible that when sewage has dried on the surfaces of pipes, bacteria may be separated as dried particles and carried some distance by currents of air passing through the pipes. The following experiments were designed to ascertain whether there are any scientific facts on which to base these beliefs."

Major Horrocks' investigations were carried out at the fortress of Gibraltar. They consisted, in the main, in the exposure of Petri plates,—shallow glass dishes, filled with a nutrient medium, (nutrose agar),—in pipes, ventilating chambers, etc., over normal sewage or sewage specially infected with particular bacteria. After a given time the dishes were removed to an incubator and any germs which had fallen on them while in the pipe were identified by appropriate tests.

In the first series of experiments the *Bacillus prodigiosus* was used, a peculiar bacterium which forms characteristic red colonies on agar plates. An elbow was attached to one end of a 2-foot length of 6-inch pipe and a half-S trap to the other. On the upper side of the trap was set up a vertical stack 8 feet high. Plates were suspended in the vertical pipe, and soapy water, inoculated with an emulsion of *B. prodigiosus*, was poured through the horizontal pipe into the trap. After two hours the plates were removed from the vertical pipe, the highest of them having been placed 9 feet above the flowing liquid. Colonies of *B. prodigiosus* appeared on every plate. A similar experiment was then carried out with a catch pit on the storm water system of the town. An emulsion of *B. prodigiosus* was poured into the pit which was actively bubbling and fermenting. Plates suspended above the liquid for twenty-four hours showed numerous colonies of *B. prodigiosus*, while others exposed outside the pit did not.

A second series of experiments dealt with the carriage, by the air, of bacteria detached from dried surfaces. Three 2-foot lengths of 6-inch pipe were laid on the ground, and their interior was thoroughly wetted with a rich emulsion of *B. prodigiosus.* After drying, they were fitted together to form a vertical stack attached to a horizontal pipe through which sewage flowed slowly to keep up an air current. Plates suspended in the vertical pipe for 20 minutes were studded with colonies of *B. prodigiosus,* while control plates exposed to the air were free from such organisms.

The third, and most detailed, series of experiments dealt with the infection of air from flowing sewage. Repeated in various forms the essential points were as follows. Sewage, inoculated with cultures of the typhoid bacillus or of *B. prodigiosus,* was allowed to flow for half an hour through a horizontal 6-foot pipe to which a vertical pipe was connected at some intermediate position. Plates were exposed in the vertical pipe, usually for 24 hours, but in a few cases for 20 minutes only. The bacteria in the liquid flowing through the horizontal pipe were regularly recovered from the plates suspended in the vertical pipe. In some cases the vertical distance of the highest plate above the liquid was 11 feet 9 inches. A few very striking tests were made with actual drainage systems. Emulsions of *B. prodigiosus* were flushed out from water closets in two buildings and plates suspended in various parts of the ventilating pipes showed the characteristic colonies. These plates were exposed for 24 hours and the specific bacteria appeared fifty feet above the water closet in one case. A third experiment was made with a series of manholes and inspection chambers on the drainage system of a hospital block. An emulsion of *B. prodigiosus* was flushed into the sewer from one set of water closets and plates were exposed at various points. Those in open connection with the sewer showed characteristic colonies, while in disconnected inspection chambers none were found. Most striking of all, an unsuspected connection was discovered by the presence of the germ in one chamber where it was not expected. In some of the experiments, the plates were exposed for twenty minutes only.

The investigator then exposed plates in the ventilating pipe of the Military Hospital for 24 hours and in the inspection chamber of the main sewer of the town for 4 hours without adding any special bacteria to those normally present in the sewage. *B. coli,* the characteristic sewage organism, was found in both cases. Finally he made up a suspension of the stool of a typhoid patient, in 2 gallons of water and passed it 12 times slowly through a half-S trap. Plates suspended in a vertical pipe connected with the trap showed several colonies of the typhoid bacillus at heights of 2 feet and 3 feet 6 inches above the trap.

Major Horrocks' principal deduction from these experiments was stated as follows "Specific bacteria present in sewage may be ejected into the air of ventilation pipes, inspection chambers, drains and sewers by (a) the bursting of bubbles at the surface of the sewage, (b) the separation of dried particles from the walls of pipes, chambers and sewers, and probably by (c) the ejection of minute droplets from flowing sewage."

Very recently Dr. F. W. Andrewes of the English Local Government Board has extended and confirmed Major Horrocks' work in a still more striking manner. (Report on the Micro-Organisms present in Sewer Air and in the Air of Drains. Supplement to the Thirty-sixth Annual Report of the Local Government Board containing the Report of the Medical Officer for 1906-07, page 183). Dr. Andrewes found by the use of the differential fermentation tests devised by Mr. M. H. Gordon and so brilliantly applied by himself to the streptococci, that a number of cocci isolated from sewer and drain air were of characteristic sewage type and were different from those found in street air. Colon bacilli were also isolated from the air of a large drain and finally Horrocks' experiments with *B. prodigiosus* were repeated with similar results. The test organisms were recovered in large numbers at points of vigorous local splashing, and they were found once at a distance of 390 feet from the point of infection.

According to accepted opinions in Germany and the United States, the conclusions which might naturally be drawn from these investigations as to the possible danger of bacterial infection from sewer air were really revolutionary. In some quarters the Gibraltar experiments have provoked almost a return to the extreme dread of sewer air which characterized sanitary opinion thirty years ago. The Journal of the American Medical Association, (XLVIII, 1896), in commenting editorially upon Major Horrocks' experiments said in its issue of June 1, 1907: "He found, too, that typhoid bacilli could be given out by fresh sewage flowing through a well-drained sewer under natural conditions independently of bubbles and the separation of dried particles from the walls. The sewer peril, therefore, still exists and disconnecting traps are sanitary necessities. It is possible that we may still have to look to sewer emanations as the occasional cause of mysterious outbreaks of disease. Air-borne typhoid is a reality under other conditions, and apparently we shall have to recognize a possibility, though perhaps a remote one, of its conveyance by the old-fashioned sewer gas." In the Illinois State Board of Health Bulletin for May-June, 1907, the results of Major Horrocks were cited in defense of the statement made in a previous bulletin that: "There is no doubt, also, that sewer gas is a carrier of diphtheretic poison and that many outbreaks hence hold close relationship with defective drainage, sewers and cesspools," a statement which had been criticised by a reviewer in the American Journal of Public Hygiene, (XVII, 130 and 262).

A more conservative view on the other hand was expressed by the most competent sanitary authorities. Dr. C. V. Chapin of Providence, for example, reviewed Major Horrocks' paper as follows

"It has of late been believed that the chance of the transmission of the infectious diseases by sewer air is nil. A number of examinations have been made which have indicated that sewer air is comparatively free from germs, and attempts to isolate pathogenic bacteria from the air of sewers have given negative results. A recent work by Horrocks (Public Health, May, 1907, page 495), indicates that pathogenic germs may be carried by sewer air. Major Horrocks, among other numerous experiments, inoculated the sewage of a large military hospital at Gibraltar with a culture of *B. prodigiosus.* The culture was put into the water closets and the bacillus was recovered on plates suspended in the top of the soil pipe, in catch basins, and in manhole openings in the street many feet distant.

The experiments were carefully conducted, and control plates showed that the organism was not found in the air of Gibraltar. One should not, however, hastily jump to the conclusion that sewer air is commonly a vehicle of infection. There is practically no clinical evidence to show that typhoid fever and other infectious diseases are transmitted by sewer air, and, indeed, the evidence that diseases in general are often air-born is very slight. There is on the contrary evidence to show that minute infected droplets, or dust particles may float in the air in considerable numbers without causing disease. Until this subject has been further studied it is to be hoped that health officers will not be in a hurry to resuscitate the sewer gas bogey." (American Journal of Public Hygiene, XVII., 296).

III. REPETITION OF HORROCKS' EXPERIMENTS.

Experimental results which conflict with common experience may justly be received with some scepticism. Dr. Chapin, and others who hold with him, have ground for feeling that if bacteria are easily carried by sewer air there should be sound epidemiological evidence of such transmission. Further more, it must be remembered that all previous examinations of sewer and drain air under normal conditions have shown it to be singularly free from germ life and have indicated that the bacteria present are as a rule air forms rather than those characteristic of sewage.

Nevertheless experiments carried out with such apparent care as those made at Gibraltar and in England deserve careful consideration. The eminent position of Major Horrocks' and Dr. Andrewes lends great weight to their conclusions; and the negative results of the control experiments reported make it unlikely that the work could have been vitiated by any experimental errors. The conditions in Major Horrocks' experiments differed somewhat from those studied by other observers. In particular the promotion of active bubbling by the addition of soap formed a part of most, though not all, of his tests. This particular phase of the subject was not studied in my earlier work, as I used the ordinary sewage of Boston as it flows in the sewers, and this sewage is rendered hard by the leakage of sea water and does not easily foam. Again, different students of this problem have adopted somewhat different methods of isolating bacteria. Here Major Horrocks' procedure was less careful than might have been desirable. The method of exposing plates freely to the air may easily lead to contamination. In arranging an open plate in a wire cage and letting it down a ventilating pipe, an experimenter who has been working with *B. prodigiosus*, for example, runs many chances of contaminating the plate from hands or clothing. With long periods of exposure, such as twenty-four hours, the danger of contamination from dust or flies is of even more serious importance.

In the autumn of 1907 I began a new series of experiments, with the idea of clearing up the apparent contradiction between Major Horrocks' results and my own; and first I attempted to repeat Horrocks' experiments as closely as possible. A preliminary series of tests was made in a boat chamber of the main sewer of the South Metropolitan District of Boston. The boat chamber is entered from the side by a flight of about twenty-five stone steps extending downward from the street; and the stream of sewage flows by the bottom at times of low flow and backs up the steps in a stagnant eddying pool when the sewer is more nearly full.

On October 8, 1907, Petri plates, flat dishes 2.5 inches in diameter, containing a nutrient medium, were exposed for varying periods of time on the second step above the sewage which was standing at a high level. The plates were made with litmus-lactose agar and after exposure were incubated at 37°; so that any organisms which fell upon them could develop into colonies. The acid forming organisms characteristic of sewage, (*B. coli* group), could thus be easily detected.

The following numbers of colonies were counted on plates exposed for various periods; 5 minutes, 12 colonies; 10 minutes, 10 colonies; 15 minutes, 10 colonies; 20 minutes, 30 colonies; 25 minutes, 14 colonies; 30 minutes, 23 colonies; 35 minutes, 20 colonies; 40 minutes, 12 colonies; 45 minutes, 30 colonies; 50 minutes, 30 colonies; 55 minutes, 33 colonies; 60 minutes, 34 colonies. Control plates exposed in the street above showed 57 colonies after 35 minutes and 80 colonies after 60 minutes. In no case did any red colonies of sewage bacteria appear.

On October 18, this experiment was repeated, but the plates were exposed on the ninth step above the sewage stream. The flow on this day was low and the air of the street dusty. All counts were higher. The total number of colonies, and the number of red colonies, found after various periods, were as follows: In the boat chamber: 5 minutes, 15 colonies, 6 red colonies; 10 minutes, 47 colonies, 16 red colonies; 15 minutes, 49 colonies, 16 red colonies; 20 minutes, 70 colonies, 30 red colonies; 25 minutes, 170 colonies, 34 red colonies; 30 minutes, 141 colonies, 36 red colonies; 35 minutes, 133 colonies, 28 red colonies; 40 minutes, 250 colonies, 50 red colonies; 45 minutes, 240 colonies, 60 red

colonies; 50 minutes, 300 colonies, 75 red colonies; 55 minutes, 250 colonies, 71 red colonies; 60 minutes 225 colonies, 50 red colonies. In this series *B. coli.* was isolated and identified from each plate. Control plates, exposed in the street above for 20 minutes showed 250 colonies, and 20 red colonies with *B. coli* present. It seemed therefore probable that the bacteria in the boat chamber came from street dust blown down the steps.

On October 25, plates were exposed at different points on the flight of steps leading from the boat chamber to the street. Colon bacilli appeared in each case. On the tenth step above the sewage the counts for different periods of exposure were as follows: 5 minutes, 64 colonies, 2 red colonies; 10 minutes, 60 colonies, 10 red colonies; 15 minutes, 66 colonies, 7 red colonies; 20 minutes, 120 colonies, 7 red colonies; 25 minutes, 170 colonies, 16 red colonies; 30 minutes, 74 colonies, 23 red colonies; 35 minutes, 48 colonies, 6 red colonies; 40 minutes, 75 colonies, 5 red colonies; 45 minutes, 110 colonies, 16 red colonies; 50 minutes, 114 colonies, 18 red colonies; 55 minutes 161 colonies, 14 red colonies. The plates on the other steps were exposed for 20 minutes only, and showed after that period the following numbers: on the 13th step, 54 colonies and 4 red colonies; on the 15th step, 74 colonies and 5 red colonies; on the 17th step, 68 colonies and 6 red colonies; on the 19th step, 70 colonies and 12 red colonies; on the 21st step, 94 colonies and 10 red colonies. Plates exposed on the top step were uncountable. The total number of bacteria, and the number of colon bacilli increased in proportion as one approached the street and left the sewage behind. The principal source of intestinal bacteria was clearly street dust rather than sewer air.

These preliminary tests, as far as they went, furnished no evidence that the air of the boat chamber was polluted by bacteria from the sewage stream. The next series of experiments was carried out with a pipe system modeled as closely as possible after one of the systems used in Horrock's investigation. Its general arrangement is shown in Figure 1. It consisted of a half-S trap of 6-inch tile drain pipe, connected with a bend. Just above the trap was attached a horizontal stack composed of four 2-foot pieces of 6-inch pipe. In each experiment a foaming emulsion of soap and tap water was prepared and infected, either with a culture of *B. prodigiosus*, a culture of *B. coli* or a suspension of feces. This liquid, to a volume of four liters, was poured into the open end of the bend and through the trap. Plates were suspended at four levels in the vertical pipe, 2 feet, 4 feet, 6 feet and 8 feet above the surface of the liquid in the trap. Nine control plates were exposed in different parts of the laboratory at points which were approximately the same in each experiment. The period of exposure was 1 1-2 hours in experiments 9, 10 and 11, and 2 hours in all other cases.

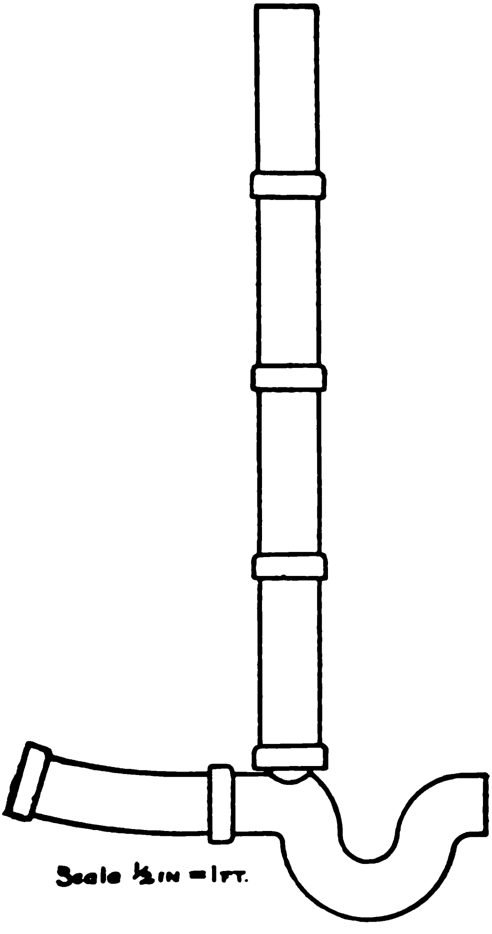


Figure 1.—Diagram of Pipe System used in repeating Major Horrocks' Experiments.

The results of these experiments, as regards total colonies on the plates, are shown in Table I. below.

TABLE I

NUMBER OF COLONIES ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM OUTSIDE

No. of Experiment	Material	Plates in Pipe. 1	2	3	4	Plates in Room 5	6	7	8	9	10	11	12	13
1	*B. prodigiosus*	20	30	26	48	—	—	68	90	118	67	88	—	60
2	Faeces	5	4	4	2	5	4	1	3	4	4	1	1	6
3	*B. prodigiosus*	77	69	77	89	140	190	136	301	175	540	254	322	182
4	*B. prodigiosus*	112	94	106	94	—	226	—	244	163	598	309	337	194
5	Faeces	26	15	0	62	8	17	6	5	13	37	30	24	21
6	*B. prodigiosus*	780	790	540	780	1080	840	1030	980	1080	2940	2400	1690	1290
7	*B. prodigiosus*	326	148	212	153	300	420	600	600	480	540	1000	720	600
8	*B. coli*	0	0	0	0	18	12	13	—	11	14	10	20	12
9	*B. prodigiosus*	44	22	30	38	106	122	102	91	94	280	172	120	74
10	*B. coli*	4	1	0	1	6	8	4	1	2	22	10	4	—
11	*B. coli*	7	0	10	3	17	11	12	10	7	9	10	8	12
12	*B. coli*	5	6	5	5	9	12	8	7	16	4	11	10	6
13	*B. coli*	10	10	8	3	9	16	9	12	9	7	5	5	14

Plates 1—4 in each case were the ones suspended in the vertical pipe above the infected liquid. 1 was 2 feet above, 2, 4 feet above, 3, 6 feet above, and 4, 8 feet above its surface. No. 13 was just outside the inlet of the bend into which the liquid was poured. Nos. 11 and 12 were just outside the outlet of the trap from which it flowed. Nos. 5—10 were in other parts of the laboratory.

The pipe system was taken to pieces and disinfected by washing the inside of each piece with corrosive sublimate solution after each experiment.

These total counts show that in general the bacteria in the pipe fluctuated with the general bacterial content of the laboratory, being somewhat lower on the whole, as would naturally be expected. The important thing, however, is the distribution of the specific organisms with which the liquid in the pipe had been infected. When suspensions of feces or of *B. coli* were used, the plates after exposure were incubated at 37 degrees and acid colonies present were examined to see whether they corresponded with the intestinal forms. When a suspension of *B. prodigiosus* was used, plates were incubated at 20 degrees and examined for characteristic red colonies. This difference of incubation temperature accounts for the much larger number of total colonies shown for *B. prodigiosus* tests in Table 1, since these were 20 degree counts.

The result of the tests as regards the distribution of specific organisms is indicated below:

TABLE II

DISTRIBUTION OF COLONIES OF *B. COLI* ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM

	Plates in Pipe				Plates in Room								
No. of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13
2	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	—	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	3	2	0	1	0	0	0	0	0	0	0	0	0
13	5	2	1	1	0	0	0	0	0	0	0	0	0

In no case were colonies of colon bacilli apparent on plates exposed to the general air of the laboratory. In the first five experiments none of the specific bacteria appeared in the pipe; but in each of the last two experiments *B. coli* appeared on three of the four plates exposed in the pipe, in greatest numbers, (3 and 5 colonies, respectively), on the plates nearest the infected liquid.

TABLE III

DISTRIBUTION OF COLONIES OF *B. PRODIGIOSUS* ON PLATES EXPOSED IN VENTILATING PIPE AND IN ROOM

	Plates in Pipe				Plates in Room								
No. of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	0	0	0	0	0	0
6	6	3	1	1	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	0	0	1	0	0	0	0	0	0	0	0	0

The results of the tests carried out with *B. prodigiosus* were essentially the same, as indicated in Table III. In three tests no characteristic colonies appeared on any plates; in the other three tests positive results were obtained in the pipe. The plates placed two feet above the infected liquid showed 6, 3 and 1 colony respectively. One plate four feet above showed three colonies. A single colony appeared on two occasions, six feet and eight feet above the liquid.

IV. OBSERVATIONS ON THE VELOCITY OF AIR CURRENTS NECESSARY TO TRANSPORT BACTERIA

Granting that bacteria may be discharged from the surface of a foaming liquid into the air above, it seemed *a priori* probable that even slight currents of air could transport them to almost any distance. I wished however to test this presumption by actual observation; and a few experiments were conducted with this end in view.

The velocity of an air current which will just carry a minute solid body must exceed the power of gravity upon the body. It is clear that bacteria can be carried upward through a pipe by a current, of a velocity just exceeding the rate at which the bacteria would fall in quiet air. The latter phenomenon, the falling of small particles through the air, takes place according to Stokes' law, which is expressed as follows:*

$$v=\frac{2}{9}\,\frac{gr^2}{m}\,(o-p)$$

Where v is the velocity of a particle (a sphere) of radius r and density o falling through a fluid of viscosity m and density p; g is the gravitation constant. Calling $g=980$; p (for air at about 20° C)$=.00018$ and calling the density of the falling particles$=1$ which is approximately correct for the bacteria, the equation becomes,

$$v=1200000\ r^2$$

Since all the quantities are expressed in C. G. S. unites v is in centimeters per second. Hence a sphere of density 1 and radius

---

[*] I am indebted to the kindness of Prof. Gilbert N. Lewis of the Massachusetts Institute of Technology for the application of this formula.

.001 cm. will drop through the air at the rate of about 1.2 cm. per sec. A sphere of radius .0001 cm. will fall .012 cm. per sec., etc.

A small bacterium like *B. prodigiosus*, has a radius somewhat less than .0001 cm. and should therefore fall through quiet air at a rate a little under .012 cm. per second, which is equivalent to about 17 inches per hour. An air current of even such slight velocity as this might therefore be expected to carry bacteria.

In order to test this point I had an opening bored into the side of a large bottle so that a rich emulsion of a culture of *B. prodigiosus* could be sprayed into the bottle at about its center. The neck of the bottle was closed by a cork stopper perforated to receive a glass tube of 1.7 cm. inside diameter. This tube in the first experiment was 75 cm. long, In the second and third experiments a smaller flask was used instead of the bottle and the tube passing through the stopper was only 10 cm. long. In all other respects the arrangements were the same.

The precedure in making an experiment was as follows; the top of the glass tube, (which has previously been sterilized), was connected by sterile tubing with the inlet of a Culture Bottle, (described later in Section V). An emulsion of *B. prodigiosus* was sprayed into the flask and a measured amount of the air in the flask was drawn very slowly through the 1.7 cm. glass tube, and the much smaller rubber tubing, into the Culture Bottle. The air was aspirated by means of a suction bottle from which the outflow was regulated by a pinchcock or by a capillary tube. In each experiment several samples of air were collected in this way at progressively increasing rates. The presence of *B. prodigiosus* colonies in the Culture Bottle showed that germs had been drawn up through the 1.7 cm. tube, at an average linear rate determined by dividing the rate of overflow from the suction bottle by the area of the tube, (2.3 square centimeters).

In the first experiment conducted, four one-liter samples were drawn through the long tube in 3, 6, 18 and 43 minutes, respectively. *B. prodigiosus* colonies appeared in great numbers in the culture bottles; 9000 per liter appeared in the three minute sample 3100 in the six-minute sample; 4250 per liter in the 18 minute sample; and 3300 per liter in the 43 minute sample. The linear flow through the 1.7 cm. tube in the four cases was approximately 5.5 cm. per sec., 2.7 cm. per sec., .9 cm. per sec. and .39 cm. per sec.; or 7920 inches per hour; 3900 inches per hour; 1300 inches per hour and 560 inches per hour. These rather high rates of flow evidently carried the bacteria in great numbers.

A second series of experiments was carried out as noted above with a smaller apparatus, arranged for the examination of smaller volumes of air, drawn up at lower speeds. 100 cc. samples were examined in this series and four rates were tested as follows; .07 cm. per sec., .08 cm. per sec.; .28 cm. per sec.; and .56 cm. per sec.; corresponding to rates of 100 inches per hour, 115 inches per hour, 403 inches per hour and 806 inches per hour. A single colony of *B. prodigiosus* appeared in the Culture Bottle of the last series and none in the others. It appeared as if the limiting velocity which would just carry bacteria had been reached.

The third series of experiments, however, showed that this was not the case, and the failure to find bacteria in this instance must be attributed to imperfect distribution of the emulsion sprayed into the flask.

The third series of tests was made in exactly the same way as the second, except that a wider range of air velocities was included. Ten samples were examined, the velocities being indicated in Table IV. below.

TABLE IV

VELOCITY OF AIR CURRENTS CAPABLE OF CARRYING BACTERIA

Number	Time for 100 cc in minutes	Velocity in 1.7 cm. tube	
		Centimeters per second	Inches per hour
1	32	.05	72
2	32	.05	72
3	15	.11	158
4	15	.11	158
5	12	.14	202
6	6	.28	404
7	3.3	.50	720
8	3	.56	808
9	2	.83	1195
10	1.3	1.28	1843

In every case large numbers of *B. prodigiosus* colonies appeared in the Culture Bottles. 1600 per 100 cc. were counted in Experiment 1 and 800 in Experiment 2; at the higher rates the number of colonies was so large as to be uncountable.

My experiments did not extend to the minimum air velocities which should theoretically be adequate to transport bacteria, (17 inches per hour). They did show that currents a little over four times as strong, (72 inches per hour), would carry enormous numbers of bacteria in the form in which they are discharged in the fine spray from an atomizer. There was a slight inaccuracy in my observations due to variations of head in the suction bottle. Calculation and control experiments showed that this error amounted to 40 per cent. at some of the higher rates, the actual velocity at the beginning of the experiment being by that amount in excess of the mean velocity for the test. At the least velocity, however, this error did not exceed 10 per cent.; and it is safe to conclude that air velocities of less than .07 cm. per second or less than 100 inches per hour, will carry bacteria in the form in which they are sprayed from an atomizer.

Applying the formula for velocity of falling particles, previously quoted, it appears that the droplets containing the bacteria in these experiments must have been less than .0005 cm. in diameter. If the bacteria are discharged from the surface of foaming liquids in droplets as small as this, it is clear that they may be transported by air currents of velocity as low as 100 inches per hour.

V. PRELIMINARY TESTS OF QUANTITATIVE METHODS FOR ENUMERATING BACTERIA IN AIR

The general result of the experiments reported in Sections III and IV was to confirm the main contention of Major Horrocks,—that specific bacteria may be ejected from a foaming soapy sewage into the air above, and once in the air may be carried to considerable distances. The proportion of positive results obtained in Section III was small, however. With an exposure of two hours over a soapy liquid richly inoculated from artificial cultures, a total of 31 specific bacteria were isolated from 52 plates. The question at once suggested itself whether the whole question at issue might not be a quantitative one. Horrocks, by exposing plates over infected sewage, found that some of the bacteria present could be isolated from the air. Other observers who had examined sewer and drain air under natural conditions by quantitative methods had failed to find sewage bacteria in appreciable numbers. It might be possible that a few bacteria do get into the air above foaming sewage; but that their number is so small as not to effect the bacterial content of the air as a whole, as determined by ordinary quantitative methods. This appeared to be the next point for investigation.

Before attempting such careful quantitative studies as seemed necessary for clearing up the contradictions which surround this subject, it was obviously important to make a careful test of the accuracy of the bacteriological methods involved.

The development of bacteriological methods for the examination of air has not attracted wide attention in recent years; and this branch of bacteriology is far behind the related subject of water bacteriology in its technique and interpretation.

The bacteriological examination of air goes back in its origin to the earliest days of the science. In 1860 Pasteur filtered air through asbestos, washed out the material collected on the filtering material and examined it under the microscope. This was a crude and very imperfect method as far as the bacteria were concerned. At about the same time, however, he developed another process, cumbrous, but of considerable accuracy. He heated flasks of nutrient media so as to sterilize them and drive out the air and while still hot, sealed the necks of the flasks. When air was to be examined the narrow neck of a flask was broken. A more or less definite volume of air rushed in and any germs present fell into the liquid and there multiplied. The number of flasks, out of a series, which showed bacterial growth, gave a measure of the number of organisms in the air. This was one of the methods employed by the French bacteriologist, Miquel, in his numerous and important investigations. He drew air through flasks of nutrient liquid, (1876), placing a filter of glass wool at the outlet of the flask to catch any germs which passed the liquid.

In 1881 Robert Koch introduced the plate method of bacterial cultivation which depends on the fact that bacteria in a nutrient jelly grow and multiply so as to form visible colonies, by counting which, the number of individual bacteria originally present, is determined. Koch himself applied his method to the examination of air by placing a culture plate of nutrient gelatin at the bottom of a glass cylinder in which a known volume of air was allowed to settle quietly. The number of colonies corresponded in a general way to the bacterial content of the air in the cylinder, but the method was obviously very inaccurate from the quantitative standpoint.

In 1883 Hesse attempted to improve the solid culture method by spreading his nutrient medium over the inside of a long horizontal glass tube and drawing a measured amount of air slowly through it. Most of the bacteria present settled out on the walls and formed colonies which could be easily enumerated. The tube was a cumbrous apparatus, however, and it was doubtful whether the bacteria did all settle out unless the velocity was extremely slow.

In 1888, Petri introduced the method which has since been most widely used. He drew a measured amount of air through a layer of fine sand, which he found would retain most of the bacteria present by adhesion to its surfaces. He then washed the bacteria off by shaking the sand in sterile water, distributed known portions of the water in Koch plates and counted the colonies. (R. J. Petri, Eine neue Methode Bacterien und Pilzsporen in der Luft nachzuweisen und zu zählen, Zeitschrift fur Hygiene, 1888, III 1). At about the same time that Petri was working, Frankland in England independently developed a similar method in which sugar was used as a filtering material instead of sand. In the same year, 1888, Sedgwick and Tucker devised a simple and ingenious apparatus for carrying out air examination by this general method, which has since come into common use in this country.

For the last twenty-five years almost nothing has been added to our knowledge of methods for bacteriological examination of air. Workers have relied almost exclusively on two procedures, the simple exposure of plates and the sand filter method. The former more primitive method was the one used by Horrocks. It offers an extremely delicate test for specific kinds of bacteria; but as pointed out above, it is open to grave dangers of contamination. Furthermore, it has no quantitative basis, since the number of bacteria found is not related to any particular volume of air. The other method in common use is a modification of the sand filter method of Petri. It involves the filtration through asbestos, sand, sugar, etc., of a measured volume of air; the washing of the filtering material with sterile water; and the plating of aliquot portions of the wash water in nutrient media. Petri recommended sand between .25 and .5 mm. arranged in two layers each 3 cm. deep, in a tube 1.5-1.8 cm. in diameter. He stated that the rate of filtration should not exceed 10 litres in 1-2 minutes. In recent years we have had no careful studies of the extent to which bacteria may be drawn through sand and lost under given conditions; and there has arisen some scepticism as to the reliance to be placed upon the whole procedure. In the most important investigation of air recently carried out in this country, the study of the air of the New York subway, Soper used both the plate method and the sand filter method. The sand grains used were "about half a millimeter in diameter" and the sand layer 3 cm. deep. (Technology Quarterly, XX, 58). In discussing these methods, in another paper this author said "as is well known, there is no precise way to determine the numbers of bacteria in air." (Journal of Infectious Diseases Supplement No. 3, 1907, p. 82.)

Obviously if the sand filter allows any important proportion of bacteria to pass, the results of the observers who reported low bacterial numbers in drains and sewers must be discounted. In my own earlier work, reported to the National Association of Master Plumbers in 1907, I relied upon the sand filter method; and in view of the results of Major Horrocks, it seemed desirable to revise the detail of the technique with considerable care. In the course of the experiments I developed a modified method of air examination which seems to combine the quantitative results of sand filtration with the directness and simplicity of the plate method. Hesse did this after a fashion by slowly aspirating air through a long roll-tube, the walls of which were covered with melted gelatin. There was, however, a possibility in such an apparatus that bacteria might be drawn through without settling out on the walls. My method was really a modification of Hesse's with an increase in the size of the culture vessel relative to the sample of air; or from another standpoint, it was a return to the original procedure of Koch with such precautions as would prevent contamination and secure quantitative results.

I used two liter-and-a-half bottles, arranged as shown in Figure 11. On the bottom of each was a layer of nutrient gelatin and the tubing was adjusted so that a measured volume of air could be drawn through the two bottles in succession, by the action of a water-suction bottle, shown inverted on the right of the figure. In practise any desired amount of water, generally one liter, is placed in the suction bottle and by slowly inverting it, a corresponding volume of air is drawn from the bottom of the second culture bottle. The same volume of air passes from the bottom of the first bottle into the top of the second, and from the outer air into the top of the first bottle. A known amount of air is thus drawn into the first bottle and the bacteria present settle out and form colonies on the gelatin. The volume of air examined being less than the capacity of either bottle, most of the bac-

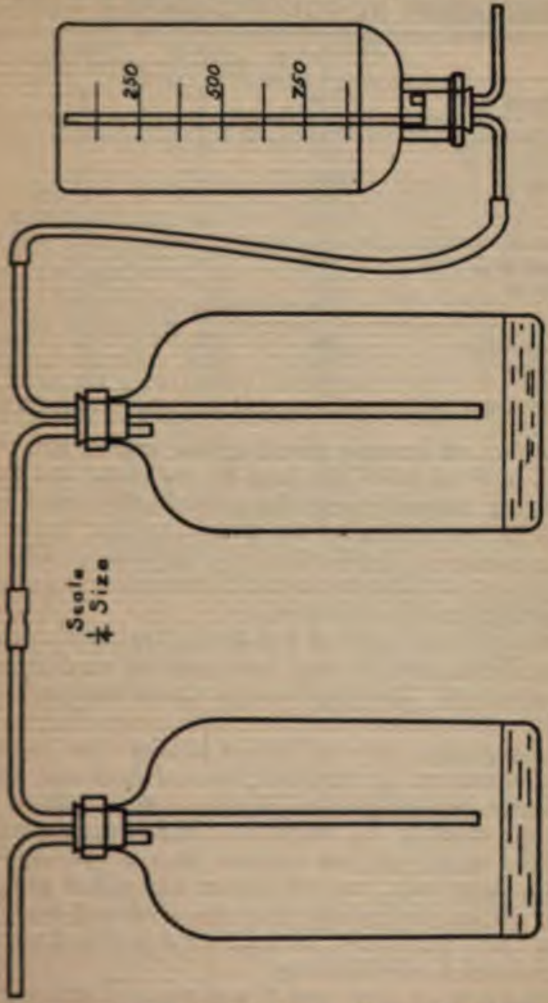


FIGURE II.

Diagram of Apparatus used in the Culture Bottle Method of enumerating Bacteria in Air teria collected remain in the first. A few, which are carried down by direct short currents, are caught in the second bottle. The results of a few examinations made by this method are shown in Table V below.

TABLE V
AIR EXAMINATION BY CULTURE BOTTLE METHOD

Air	Sample, c.c.	Colonies first bottle	Colonies second bottle	Bacteria per liter
Normal Street Air	1500	4	0	3
Air above foaming soapy emulsion of *B. prodigiosus*	1000	1	0	1
	1000	1	1	2
	1000	1	0	1
	1000	3	0	3
	1000	1	0	1
Air sprayed with suspension of *B. coli*	100	73	1	740
	100	984	91	10750
	100	394	69	4630
Air sprayed with suspension of *B. prodigiosus*	100	492	3	4950
	100	320	34	3540
	100	1188	120	13080

The number of bacteria reaching the second bottle is evidently small, in most cases less than 10 per cent., and the number lost by being drawn through the second bottle must be negligible. With the exception of the possibility that bacteria may settle on the sides of the bottles, the method should give a complete account of all bacteria present which will grow under ordinary conditions of cultivation.

The Culture Bottle method was devised primarily as a check on the Sand Filter method; and two types of sand filters were used for comparison. The first was the classic Sedgwick-Tucker apparatus which consisted of a glass tube 15 cm. long and 4 cm. in diameter, opening at one end into a smaller tube 10 cm. long and .5 cm. in diameter. A layer of 5 cm. of sand was supported in the small tube by wire gauze. A measured amount of air was drawn through, entering the larger tube and passing out through the sand. The sand, with the bacteria filtered out, was shaken down into the large tube, melted gelatin was added and by rolling the tube on ice, the gelatin with the sand and bacteria was cooled on its inner surface. The sand used in this filter was between .5 mm. and 1.0 in diameter.

The other type of filter tested was the one which I used a year ago. It consisted of two short tubes 1.5 cm. in diameter, arranged in tandem, each containing 2.5 cm. of sand, between .1 mm. and .3 mm. in diameter. The sand in each tube was supported by bolting cloth on a perforated rubber stopper and the tubes were connected by rubber tubing. The apparatus is shown in Figure III. After drawing air through this filter, the sand from each tube was shaken out into ten cubic centimeters of sterile water and after thorough agitation aliquot portions of the water were plated. This method is essentially the one used by Soper and by most recent observers.

Each of these filter methods is open to possibilities of error. Bacteria may be drawn completely through the filtering layer in either case; and in the second method there is danger that bacteria filtered out may not be separated from the sand or bolting cloth. My object was to find out how serious these errors are by direct comparison with the Culture Bottle method. For this purpose a number of examinations were made, of normal air, and of air artificially infected with bacteria by spraying with emulsified cultures. With the filtration method samples of 750 cc. to 1500 cc. were slowly drawn through the sand, the filtration occupying 2-3 minutes. With the Culture Bottles samples of 100 cc. were generally used and the air was drawn in more rapidly. The general results obtained may be shown best by quoting a few typical experiments in detail.

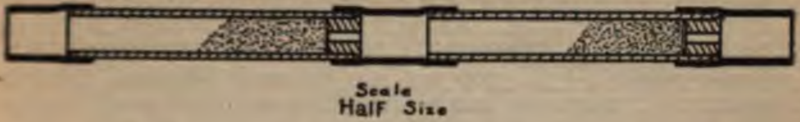


FIGURE III.
Diagram of Apparatus used in the Sand Filter Method of enumerating Bacteria in Air

Experiment III. Examinations of air of a city street on a winter's day. Four successive samples taken at intervals of perhaps fifteen minutes showed (1), 3 bacteria per liter, by Culture Bottle Method; (2), 17 bacteria per liter by filtration method, (fine sand); (3), 23 bacteria per liter by filtration method, (fine sand); (4), 94 bacteria per liter by filtration method (fine sand). Apparently the number of bacteria in the air was increasing during this experiment; but the results by the two methods are concordant.

Experiment IV. A suspension of a culture of *B. coli* was sprayed into a box and five samples taken at intervals of about ten minutes. The results were as follows: (1), 2640 per liter by filtration method, (fine sand); (2), 100 by filtration method, (fine sand); (3), 740 by Culture Bottle method; (4), 40 by Culture Bottle method; (5), 0 by sand filter method (fine sand). Evidently the bacteria were settling out rapidly. With the exception of the low sand filter count in No. 2 the results of the two methods check fairly well.

Experiment V. *B. coli* was sprayed into a box four times, at intervals of about ten minutes, a sample of the air being examined after each spraying. The results were as follows: (1), 175 bacteria per liter, by sand filtration, (coarse sand); (2), 4300 per liter by sand filtration (fine sand); (3), 4000 per liter by sand filtration, (fine sand); (4), 10,750 per liter by Culture Bottle method. Very probably the repeated spraying more than balanced the settling out and the number of bacteria in the air of the box actually increased. The first result with the coarse sand is, however, clearly too low.

Experiment VI. *B. prodigiosus* was sprayed into a box three times. The first two samples were examined after the first spraying, the third and fourth samples after the second and third sprayings, respectively. Results: (1), 15,000 bacteria per liter, by sand filtration, (fine sand); (2), 14,000 per liter by Culture Bottle method; (3), 5300 per liter by sand filtration, (coarse sand); (4), 14,000 per liter by sand filtration, (fine sand). Again the filtration method checked with the Culture Bottle method when fine sand was used, but gave low results with the coarse sand.

These experiments, and others of the same sort, seemed to indicate that sand filtration gives reasonably accurate results if the sand used be as fine as .3 mm. The crucial test of this point, however, must be made by drawing a given sample of air through sand filters and a Culture Bottle, so arranged in tandem that the bacteria which pass the sand shall be collected in the bottle. Table VI. below shows a series of such experiments and makes it clear that the efficiency of the filtration method depends upon the size of sand grain employed.

TABLE VI

RELATIVE NUMBER OF BACTERIA PASSING THROUGH SAND FILTERS AND RETAINED IN THEM

Air examined	Bacteria per liter retained in filter		Bacteria per liter passing filter
	Two 2.5 cm layers of .1 — .3 mm. sand	One 5 cm. layer of .5 — 1. mm. sand	
Suspension *B. prodigiosus*	100		2
Street air	94		1
Suspension *B. coli*	2640		12
"		175	304
"	4000		37
Suspension *B. prodigiosus*		1700	3500
"	14000		2400
Suspension, *B. coli*	40		12
"	90		15
"		165	105

In seven tests with tandem sand filters, each containing 2.5 cm. of sand, with grains between .1 and .3 in diameter, the bacteria passing the sand were,—once 30 per cent. of the number retained by the sand; twice 17 per cent., once 2 per cent., and three times 1 per cent. or less. On the other hand, in three tests with the Sedgwick-Tucker apparatus holding a single layer of sand, 2 cm. deep with grains between .5 mm. and 1.0 mm., nearly half the bacteria present passed the sand in one case and about two-thirds escaped in the other two instances.

It seems clear that sand over .5 mm. in diameter is inadequate for filtering out bacteria. On the other hand a sand finer than .3 mm. is generally efficient. It is of course obvious that sand of either size cannot operate in the removal of bacteria by any process which can properly be called straining. In an editorial discussion of the removal of fine particles from water the Engineering News, (LIX, 344), has described the phenomenon as "adhesion"; and the term deserves general acceptance in this connection. The size of the sand must affect the removal of fine particles in two ways. First in a given depth the number of surface contacts which permit adhesion, must vary inversely with the size of the particles. Second, the velocity of flow, which tends to tear off adhering particles, must, under given conditions, increase with the size of the particles. Coarse sand might therefore be used with success by filtering through a deeper layer, and by cutting down the rate of flow.

On the whole, it is clear that the Culture Bottle method, although cumbrous, is somewhat superior to the Sand Filter method, where the highest accuracy is desired. To avoid any possibility of error, I have used it in all succeeding experiments. At the same time the comparative tests reported show that the errors of the Filter method are not serious if the sand used be fine enough. The results of observers who have used the sand method, may therefore be accepted as reliable in their general conclusions.

VI. ENUMERATION OF BACTERIA IN AIR OVER FOAMING LIQUIDS.

Horrocks' experiments, and my own repetition of them, showed that specific bacteria could be recovered from the air over foaming liquids. On the other hand, quantitative studies showed that sewage bacteria are rarely present in the air of sewers and ventilating pipes under normal conditions. It was of vital importance to determine the meaning of this apparent contradiction. It seemed to me that it might be due to one of two possibilities. Either the artificial infection and the addition of soap to produce foaming, common to most, (but not all) ,of Horrocks' experiments, caused an abnormal number of bacteria to be discharged into the air; or even under such conditions the bacteria, though they may be detected by the plate method, are present in such small numbers as not appreciably to affect the air of the sewer as a whole.

In order to test this point, I set out to examine, under carefully controlled conditions, the air over liquids of various sorts. My original plan was to test sewage, with and without the addition of soap to produce foaming, suspensions of feces in water with and without soap, and artificial emulsions of specific bacteria. I began with the most severe test, which was likely to show the largest possible numbers in the air; a suspension of a rich artificial culture of *B. prodigiosus* in water, to which enough soap had been added to make it foam vigorously. The results of this first series showed such slight infection of the air, that it was unnecessary to proceed to more rigorous tests.

Eight experiments were made upon this point, in February and March, 1908. In all cases the emulsion was made with tap water, to which a large excess of soap had been added, and the germ used was *Bacillus prodigiosus.* The emulsion contained from 200,000 to 5,000,000 bacteria per c.c. in different experiments; and it was agitated so as to form a layer of foam from 1-4 in. to 1 1-2 inches deep on the surface.

In the first five experiments the infected emulsion was poured through a funnel into a glass chamber about 30 cm. in diameter and 17 cm. deep, with considerable splashing, as well as foaming. Three or four samples of air of one liter each were collected in each case from the chamber at a height of 3 cm. or less above the foam, the first being taken immediately after the liquid was poured in, the others at intervals during the next hour or so.

The results of these experiments, with those of the other three, which will be described later, are shown below in Table VII. In three of the five cases not a single colony of *B. prodigiosus* appeared in the four liters examined in spite of the fact that hundreds of thousands were present in each centimeter of the liquid below. In Experiment III. a single *B. prodigiosus* appeared in one of the four liters; and in Experiment IV. one liter showed one, and a second showed three.

The act of sampling, in drawing off four liters of air from the chamber of course created air currents across the surface of the foaming liquid in these experiments. In order to observe the effect of more active circulation of air three more experiments were made in which the foaming emulsion was poured into a glass vessel four inches deep and left open in the laboratory. The surface of the foam was a little over the edge of the vessel in each instance, and in order to make all conditions severe the samples of air were taken from a point as close to the surface of the foam as possible. Samples were taken at intervals during a half hour period. In Experiment VI. two of the four samples showed no colonies; of the other two, each showed a single colony of *B. prodigiosus.*

In Experiment VII. the samples showed counts of 2, 3, 0 and 1 colonies per liter; but all were air bacteria and none *B. prodigiosus.* In Experiment VIII. three samples examined showed counts of 2, 1 and 2 colonies per liter; but again none were *B. prodigiosus.*

It is clear from these experiments that the number of bacteria discharged into the air over an infected liquid is extremely small, even under the most favorable conditions. With an actively foaming liquid containing hundreds of millions of bacteria per liter, 30 liters of air examined showed altogether only 7 of the bacteria in the emulsion below.

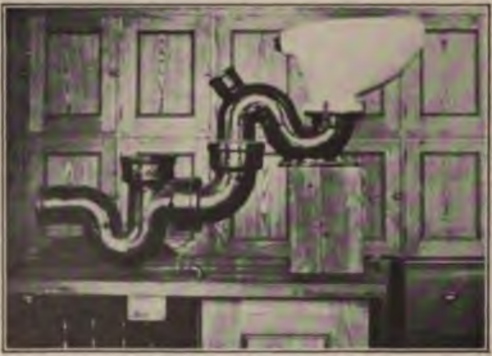


FIGURE V.
Photograph of Experimental Plumbing System.

Numbers of this magnitude can be detected by Horrock's plate method; but they would scarcely affect the general composition of drain and sewer air in a degree sufficient to be revealed by quantitative methods.

TABLE VII.

BACTERIA IN AIR OVER FOAMING LIQUIDS

	B. prodigiosus per liter				
Experiment	In liquid	In air			
1	530,000,000	0	0	0	0
2	680,000,000	0	0	0	0
3	930,000,000	0	1	0	0
4	5,000,000,000	0	1	3	0
5	1,000,000,000	0	0	0	0
6	2,700,000,000	1	0	0	1
7	1,800,000,000	0	0	0	
8	4,400,000,000	0	0	0	

VII. ENUMERATION OF BACTERIA IN PLUMBING PIPES OVER FOAMING AND SPLASHING LIQUIDS.

Major Horrocks' experiments, and the confirmatory tests reported in Section III., show that some bacteria are discharged from the surface of a foaming liquid and may be recovered from the air above. Once in the air, they may be transported by currents of quite low velocity, as shown in Section IV. On the other hand, the experiments discussed in Section VI. indicate that the numbers of bacteria discharged in this way are small. The air immediately over a quiet body of infected liquid covered with a deep layer of bursting bubbles showed only rare and slight contamination.

Under ordinary conditions the effect of foaming is reinforced by gross mechanical splashing, which might conceivably increase the tendency to discharge bacteria into the air in minute droplets. In order to test this point I made a series of experiments with the apparatus shown in Figures IV and V. It consisted of an ordinary porcelain water closet bowl set directly on an S-trap with a cleanout hole at its apex. The S-trap was connected at its lower end by a bend with an ordinary running trap.

A rich soapy emulsion of about 7 liters was made up, as in other tests, and infected with a culture of *B. prodigiosus.* This was poured as rapidly as possible into the bowl of the closet so that it rushed down through the pipe, foaming and splashing, finding its exit finally from the lower end of the running trap. A large cork stopper was placed in the clean-out hole, while the liquid was passing, but was removed immediately afterward. Liquid remained in the S-trap and closet bowl and in the running trap; and on the surface of this liquid was three or four inches of foam. A current of air passing in at the running trap and out at the clean-out was manifested by a slight cloud of vapor at the clean-out, (the water used in making up the emulsion being warm). Everything was therefore as favorable as possible for the appearance of bacteria from the infected liquid at the clean-out and in the upper opening of the running trap.

At both points samples of air were collected and examined by the Culture Bottle Method. Sampling point A, at the clean-out (See Figure IV), was about 9 in. from the liquid in the S-trap, and in the full course of a current of air from the pipe through which the foaming liquid had just passed. Sampling point B was 6 in. above the liquid in the running trap and often only 3 in. from the surface of the foam. Furthermore no attempt was made to sterilize the apparatus during the course of the experiments. Bacteria dried on the surface between two tests, (which were made three days apart), might therefore have been detached to increase the contamination of the adjacent air.

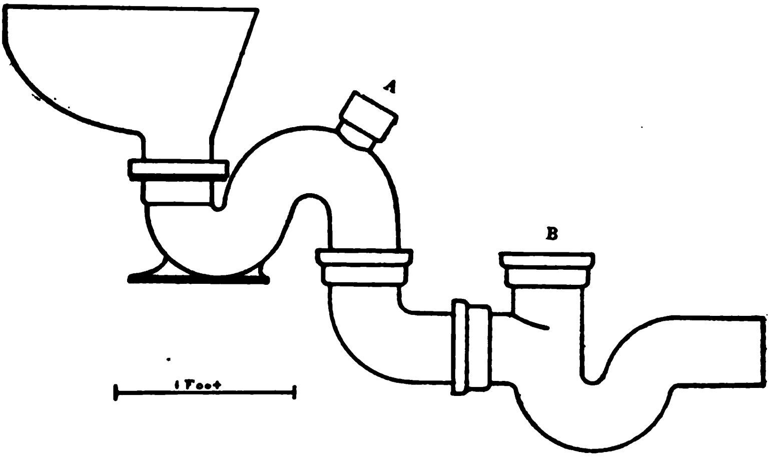


FIGURE IV.
Diagram of Experimental Plumbing System.

The general results as concerns total numbers of bacteria are shown below in Table VIII. Four to seven liters of air were examined in each Series, samples being taken alternately from the openings A and B. Sometimes the whole test was completed in fifteen minutes; sometimes the samples were taken at intervals of half an hour for a three-hour period. No important difference appeared in the results.

Table VIII. shows merely the total number of organisms in the air examined. The important thing of course was to determine the presence of the specific bacteria with which the liquid flowing through the system had been infected. All colonies which appeared in the bottles were therefore examined;

TABLE VIII.

TOTAL BACTERIA IN AIR OVER SPLASHING LIQUID

Sampling point	A				B		
I	1	1	1		0	2	0
II	1	11	1	2	1	8	4
III	3	1	1		0	1	1
IV	1	0	0		0	0	0
V	4	7	15		4	1	
VI	0	2	0		0	0	
VII	0	1	0		1	0	
VIII	2	1			0	0	

and with the exception of a single bottle all the colonies turned out to be those of the molds and common cocci of the air. In the second sample taken at the upper clean-out of the S-trap in Experiment II. the cultures proved to be *B. prodigiosus.*

TABLE IX

SPECIFIC BACTERIA IN AIR OVER FOAMING AND SPLASHING LIQUID

B. prodigiosus per liter

	Liquid	Air at A				Air at B		
I	1,300,000,000	0	0	0		0	0	0
II	300,000,000	0	11	0	0	0	0	0
III	—	0	0	0		0	0	0
IV	2,500,000,000	0	0	0		0	0	0
V	1,750,000,000	0	0	0		0	0	
VI	5,000,000,000	0	0	0		0	0	
VII	—	0	0	0		0	0	
VIII	2,100,000,000	0	0			0	0	

Table IX. shows the general quantitative results of the experiments, which may be summarized as follows: A richly infected liquid was prepared containing several billion bacteria per liter. This was beaten up with soap into a heavy foaming emulsion and was then poured rapidly through a water closet and two successive traps, splashing and foaming as it went. Forty-four liter samples of the air of the traps, were examined, from points 6 to 9 in. above the liquid. Forty-three of these samples showed none of the organisms in the liquid, and one showed a group of 11 colonies, probably derived from a single infected droplet. It appears then that under the most severe conditions that can well be devised the bacteria in infected liquids reach the air adjacent only rarely and in small numbers.

VIII. SEWAGE BACTERIA IN THE AIR OF PLUMBING PIPES UNDER NATURAL CONDITIONS.

The laboratory experiments detailed above appeared to show that although bacteria can be thrown into the air by splashing and bubbling liquids the amount of infection produced in this way is slight, even under extreme conditions. The important thing, however, is to determine what occurs in house drains and branch connections actually in use. Experiments with artificial inoculations of rich bacterial cultures must always give a somewhat distorted view of the possibilities, and no work which is not quantitative can give any idea of the practical importance of the problem.

With the cooperation of Mr. David Craig of the Sanitary Committee of the Master Plumber's Association, I therefore undertook an examination of the drain air of plumbing systems of different sorts in various Boston buildings, with a view to seeing how abundant sewage bacteria were as a matter of actual fact. Nineteen plumbing systems were selected in nineteen different buildings of various sorts, hospitals, educational institutions, tenements, public buildings, a hotel, an office building, etc. At twenty points on these nineteen systems the pipes were tapped for the examination of the air and from each point ten liters of air were collected for examination. The sampling points were selected to give as wide a range of conditions as possible. Some were on main stacks of soil pipe, some on the main stack prolonged above the roof, one on a vent pipe, several on the main house drain or on clean-outs connected closely with it. Each series of ten liter-samples was collected at intervals in a period of an hour and a half. Thus in all 200 liters of drain air were examined, representing a wide variety of conditions in nineteen different plumbing systems, and forming a fairly representative idea of the composition of house drain air.*

The general method adopted was that described as the Culture Bottle Method in Section V, above. One liter of air was drawn into two liter-and-a-half bottles arranged in tandem and the bacteria in the air were allowed to settle out and then cultivated. My object was not to determine the total number of bacteria but to isolate specific forms. I therefore replaced gelatin in the bottom of the Culture Bottles by a solution of dextrose broth, which forms the most suitable and delicate medium for the detection of sewage bacteria, of the *B. coli* and the *Streptococcus* types. The bottles were incubated at body temperature, 37 degrees, centigrade for three days. As soon as growth appeared in any bottle sub-cultures were made on litmus-lactose-ager and if any acid colonies appeared they were examined further. The *Streptococcus* type was defined as including all acid forming streptococci and the *B. coli* type was recognized by gas formation in dextrose broth, coagulation of milk, reduction of nitrates, formation of indol and non-liquefaction of gelatin.

The first test of an actual plumbing system, Series A., was made on May 27, 1908, in the Henry L. Pierce Building of the Massachusetts Institute of Technology. The sampling point

---

* Thanks are due to Mr. A. F. Stevenson for assistance in the conduct of these experiments.

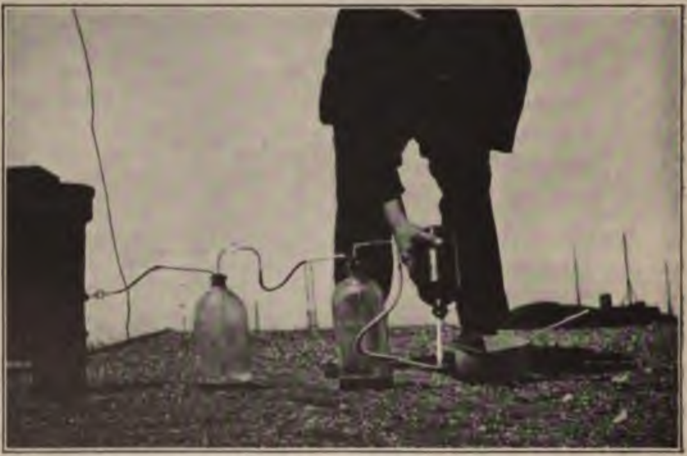


FIGURE VI.
Photograph of Apparatus used in sampling Air of Plumbing Systems in actual use

was on the main stack of soil pipe in the basement. Above there were fixtures on four floors, two water closets and two urinals on each. The plumbing was about ten years old. The number of persons using the building is about 150.

In this first test the inlet pipe of the first Culture Bottle was passed through the 3-4 in. hole drilled in the pipe directly into its interior. The hole was situated in a branch clean-out a few inches from the main stack and it soon appeared that the liquid in the pipe was running over the walls of the clean-out and dropping into the end of the collecting tube. From three of the bottles *B. coli* was isolated, but the possibility that direct infection had taken place by the trickling of a thin stream of sewage along the collecting tube led me to discard these results.

In all further work precautions were taken to prevent accidents of this sort. Short pieces of glass tubing were prepared with a bulb about one inch in diameter blown in the middle of each. One end of the tube was inserted into a rubber stopper which fitted the hole drilled in the plumbing pipe and the Culture Bottle was thus protected from direct liquid infection, unless the bulb became so full as to overflow. When this occurred, as it did in a few cases, it could easily be observed and the test excluded. The arrangement of the apparatus and the method of taking samples are shown in Figure VI.

The second series of tests, Series B, was made in the Rogers Building of the Massachusetts Institute of Technology, on May 28, 1908. The plumbing here was old, the main stacks having been installed for 40 years. Some 300 people use the building during the day time. The sampling point was on the waste from a line of four urinals on the first floor, a few feet from the main stack and in direct connection with it. Above, on the main stack, were two water closets and three urinals, and below in the basement one water-closet and three urinals. Two of the ten liters of air collected at this point showed growth in the Culture Bottles, but in neither case were intestinal bacteria present.

Series C was carried out on June 1 in the Henry L. Pierce Building of the Institute at the same point described under Series A, with the single difference that the bulb described above was placed between the pipe and the Culture Bottle to prevent direct contamination. The importance of this precaution and the propriety of excluding Series A from consideration were shown by the fact that in six of the ten tests an appreciable amount of sewage collected in the bulb. None reached the bottles however. Two out of the ten showed growth but neither contained colon bacilli or sewage streptococci.

The tests of Series D were made on June 1, in the afternoon, in Ward E of the Boston City Hospital. The sampling point was on a sink drain in the cellar a few feet distant from its entrance into the main drain. On the stack entering the main drain were two water closets, a urinal, two baths and several slop hoppers and sinks. The plumbing is about six years old. Of the ten liters examined, only one contained bacteria capable of growth at 37 degrees, and these were not sewage forms.

Series E was carried out on June 2 at the Sanitary Research Laboratory of the Massachusetts Institute of Technology on Albany street. There there is a small two-story laboratory building with a single water closet and several sinks, used by four persons. Samples were collected from the soil pipe above the entrance of the drains from the fixtures. Two liters out of ten showed growth at 37 degrees, but no intestinal forms.

Series F was again at the City Hospital on the system serving wards W and X. Samples were taken from a sink drain about two feet from the main drain in the basement. On each of the two floors above were two water closets, a sink, a slop hopper and a urinal. The system was about 12 years old and the Ward contains 28 beds. When the third sample was collected at 10:20 and the ninth at 10:55, the sink above the sampling point was discharged. In each case liquid collected in the bulb, but in neither did it pass over into the Culture Bottle. In the case of the third sample, however, *B. coli* was isolated from both the first and the second Culture Bottle. Here was the first case in which sewage bacteria were present in the drain air; and in this instance they were found in immediate contact with actively splashing liquid.

The system chosen for Series G was in the Nurses' Home of the City Hospital. The plumbing here is 22 years old and the population of the house about sixty. The sampling point was on the main stack of soil pipe on the second floor of the building. There were four water closets and four bowls above and the same below. Leaking fixtures of some sort produced a steady flow of liquid down the pipe during the whole course of the experiments, and flushes occurred at frequent intervals. Water collected in the bulb in every case but two. In collecting the fourth, eighth and tenth samples, the bulb overflowed into the Culture Bottle. All three of these samples showed *B. coli*. In addition the sewage *Streptococus* was isolated from the first sample. This is the second instance in which sewage bacteria were present in the drain air; in this case as in the one previously cited there was active splashing of liquid at the point of collection.

The tests of Series H were made on the afternoon of June 5 at the Technology Club on Newbury street. Samples were collected from the main soil pipe. Two water closets and two baths were above and two water closets and two urinals below. Growth occurred in three out of ten samples, but no intestinal forms were found.

The samples for Series I were taken on June 6, from the plumbing system in a private residence in Newbury street. The plumbing is about twenty years old and is used by six or eight persons. The sampling point was in the basement on the vent pipe from the water closet, of course connected above with the rest of the vent pipes of the system. In such a position the contact with sewage material was somewhat remote, but it seemed of interest to include one such case at least in the investigation since so much house plumbing is similarly circumstanced. Two of the ten samples showed growth, but no intestinal bacteria were found.

Series J was carried out June 8 in the Walker Building of the Massachusetts Institute of Technology. The sampling point was on the main stack of soil pipe with three urinals and various sinks above and two water closets and three urinals below. The plumbing is about 25 years old. Chemicals discharged into the stack from sinks in the Chemical Laboratories might produce some disinfectant action in this system. Water collected in the bulb three times and once passed over into the bottle. In one case growth occurred, but no intestinal forms were found.

Series K was carried out on June 10, in Ward P of the City Hospital. This is old plumbing, in place for 34 years, and like the other wards this one is occupied by 28 persons, besides nurses and attendants. On the main stack are two water closets, one urinal, one slop hopper and one bath. Samples were collected from a clean-out at the extreme end of the house drain close to the entrance of a sink drain, but some distance from the main soil pipe. The sink was flushed out during the taking of the fifth sample. This and one other sample showed growth, but no intestinal forms.

The tests of Series L were made at the Hotel Lenox on June 11. The plumbing here is eight years old and consists of a series of stacks each passing straight up through the ten floors of the hotel and receiving the wastes from a water closet, a bath and a sink on each floor. Samples were collected from a clean-out at the foot of the main stack in the basement. Three samples showed growth, but none sewage bacteria.

In Series M, (June 11, afternoon) the air of another stack at the Lenox of exactly similar construction was examined. In this case the samples were collected from the stack just above the roof. The top of the stack in tests of this sort was left uncovered and there was a strong current of air passing upward by the sampling point. Six of the ten samples showed growth, but no sewage bacteria were found. It is interesting to note that of the nine samples in the two Lenox series which showed growth, seven were molds, a phenomenon not observed in other cases.

Series N was carried out at the City Hall on June 12. The stack tested was a four-inch soil pipe passing through the roof near the northeast corner of the building; and the sampling point was just above the roof. I was unable to find out just which fixtures were connected with this stack. Two bottles showed growth, but no sewage forms.

The next series of tests, Series O, was made in the Old Court House, behind City Hall, on June 13. The system examined had been put in for about two years. It included three water closets and two bowls on one line and seven water closets, seven bowls, and four urinals on another. The sampling point chosen was a clean-out on the main drain below the first stack and above the second. Three samples showed growth, but none contained *B. coli.*

The tests of Series P were made at the Ames Building, (offices) on June 15. The sampling point was on a main six inch soil pipe just above its passage through the roof. The stack has been in use for 17 years and receives the drains from ten water closets, besides sinks and hoppers. Four of the ten samples showed growth, but no intestinal forms.

The next four series of tests were made in three tenement houses on Border street, East Boston. The plan of all three systems was the same. A four-inch house drain, running the length of the cellar, received at each end a rain water leader, and in the middle a stack of soil pipe. On the stack in each case were three water closets and three sinks, used by 15 to 20 people. The plumbing is about 12 years old.

The tests of Series Q and R were made on the main stacks of tenement houses A and B just above the roof on June 18 and 19. In Series Q two samples showed growth, in Series R none. No sewage forms were found.

Series S proved of great interest. The samples were taken on June 19 from the main house drain in the part of the pipe intended for carrying rain water from the front leader, but only about ten inches from the foot of the soil pipe. The location was thus well within reach of splashing from the liquid striking the bottom of the stack. While the first, sixth and ninth samples were being collected there were flushes in the soil pipe. From the first and ninth samples *B. coli* was isolated. There was no collection of water in the bulb in either case. Clearly the splashing of the sewage in the soil pipe produced a fine spray which was carried by the air into the Culture Bottles. It is almost of equal significance however to note that the second sample and the tenth showed no sewage forms. The first flush occurred at 11:40. At 11:45 the sewage bacteria had disappeared from the air one foot away. The second flush occurred at 12:50; and the sewage forms were gone at 1.

The tests of Series T were made in tenement house C, on June 20. A hole was drilled for sampling in the house drain just above the soil pipe as in Series S. The drain had sagged somewhat, however, and the portion of the pipe formed, as it appeared, a pocket full of stagnant and septic sewage. This should be an admirable preserve of disease germs according to the older view point. I therefore had another hole drilled further back along the house drain, twenty feet from the soil pipe and about five feet from the backed-up sewage. Two of the ten samples of air from this point showed growth but no sewage bacteria.

Series U was carried out at the Engineering A Building of the Massachusetts Institute of Technology, on June 22. Samples were taken from the main soil pipe above the roof. The system is about 20 years old and includes six water closets, twelve urinals and various sinks. No growth occurred in any of the Culture Bottles.

The general results of all the experiments are summarized in Table X below. Growth in the Culture Bottles is indicated by a minus sign. The presence of intestinal forms, (*B. coli* or sewage streptococci) is indicated by a plus sign, and when direct infection by the running over of liquid occurred the plus sign is doubled.

TABLE X

BACTERIA IN THE AIR OF DRAIN PIPES UNDER NATURAL CONDITIONS. 200 ONE LITER SAMPLES

— Bacteria present. + Sewage Bacteria present in the air. ++ Sewage Bacteria introduced by direct liquid contamination.

Sample	Series	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1							+									—			+	—	
2							—		—				—		—				—		
3						+		—			—		—	—			—				
4							++			—			—								
5									—			—			—	—	—				
6			—	—	—		—	—					—	—		—					
7		—	—		—							—				—					
8		—					++														
9								—					—		—						
10								—					—		—				+	—	
							++				—	—	—			—					

Out of 200 one-liter samples of drain air 152 contained no bacteria capable of growing at 37 degrees. 41 more showed none of the organisms recognized as characteristic of sewage. In three cases direct liquid infection took place, introducing colon bacilli. In four other cases, only, out of the 200, were sewage bacteria isolated from the air of the house drains studied. In every one of those four cases there was vigorous splashing of sewage within a few inches of the sampling point and at the moment the sample was taken. At points further removed from splashing, and at the points where splashing had occurred ten minutes before, no sewage bacteria were found. In the whole series of 200 liters of air collected from the most diverse locations on nineteen different plumbing systems, not a single sewage organism was found except where the air was exposed to immediate local infection by fine particles of spray.

IX. SUMMARY OF PREVIOUS SECTIONS AND CONCLUSIONS AS TO THE ROLE OF SEWER AND DRAIN AIR IN THE SPREAD OF BACTERIAL INFECTIONS.

The idea of the connection between sewer gas and disease dates back to the days when the cause of the infectious maladies was still unknown. Mysterious miasmatic influences were naturally enough supposed to accompany the foul odors of decomposing organic matter. When it was proved that the contagious and infectious diseases are due to the presence of microscopic plant and animal parasites, the case against sewer gas seemed less convincing.

Nägeli and many other bacteriologists showed that under ordinary conditions germs adhere strongly to moist surfaces and are not easily given off from liquids into the adjacent air. Sir Edward Frankland in England and Raphael Pumpelly in this country carried out experiments which indicated that chemicals in solution, and bacteria in suspension, might be thrown into the air from liquids by the bursting of bubbles. On this contingency the possible danger of sewer gas infection still might rest.

Actual examinations of the air in sewers, however, by Miquel in France, Petri in Germany and Carnelley and Haldane, Robertson and Laws and Andrewes in England showed that sewer air as a matter of fact contains very small numbers of bacteria and those of types common in street air rather than in sewage. Uffelmann found the same condition in the air of a house drainage system. Carnelley and Haldane and Laws and Andrewes isolated sewage bacteria in the immediate vicinity of points where active splashing occurred. As in the experimental studies of Frankland, Pumpelly and Dr. Abbott of Philadelphia there was clearly a possibility of air infection where spray was produced by some mechanical method. On the whole, however, the air of drains and sewers seemed to be of high bacterial purity and all the observers who studied normal conditions in actual sewers concluded that the danger of bacterial infection from sewer air was remote.

These results, with the absence of any reliable evidence from the study of epidemics in favor of the transmission of germs by sewer air, has led sanitarians in Germany and the United States to agree with practical unanimity that the danger of such transmission may be disregarded. In England, on the other hand, a large number, probably a majority, of sanitary experts have failed to be convinced, and have clung to the opinion that under some conditions the carriage of disease bacteria by sewer air is a practical possibility.

A little over a year ago, at the request of the National Association of Master Plumbers, I made some experiments on this problem, upon which no practical investigations had been conducted for over ten years. I used an experimental stack of four-inch soil pipe, fifteen feet in height, with a running trap at the bottom and an exhaust fan, for drawing up a strong current of air, at the top. Sewage was placed in the trap, sealing it partially or completely, or resting in the bottom without sealing it. Air was drawn over the sewage and wetted surfaces of the pipe or was bubbled through the sealed trap and the air was examined at various points in the stack above. When the air current was strong, an increase was noted in the bacterial content of the pipe air; but the increase was not striking even at high velocities and was entirely wanting with air currents of less extreme force. Only three of the characteristic bacteria of sewage were isolated from the air in the whole series of experiments. As a result of this investigation I reported that the danger of bacterial infection from drain air was but slight.

At about the same time a series of experiments on sewer air was reported to the Royal Society of London by Major W. H. Horrocks of the English Army Medical Corps. His results seemed at first sight to warrant widely different conclusions from those drawn by other observers; and it seemed necessary to re-examine the whole question with the greatest care.

Major Horrock's general method consisted in the artificial infection of the lower part of natural and experimental drainage systems with a peculiar bacterium, the *Bacillus prodigiosus*, which is not normally found in the air. He then exposed small open dishes of nutritive media, (Petri plates) in the upper part of the systems. Germs carried up in the air fell on the plates, grew and developed into visible colonies, and among these colonies he identified the particular form, *B. prodigiosus*, introduced in the liquid at the bottom. By this process he detected his test organism in a pipe 9 feet above an experimental running trap into which it had been introduced, and in the air of a catch basin of the town into which he had poured it. Similar results were obtained when the lower sections of his experimental pipe system were wetted with a culture of the *B. prodigiosus* and then dried. The dried germs were apparently detached, carried up by the air and deposited on the plates. In another series of experiments sewage, infected with the typhoid bacillus or with *B. prodigiosus*, was allowed to flow, quietly and without splashing, through a horizontal pipe to which a vertical pipe was connected at an intermediate point. Plates exposed in the vertical pipe showed colonies of the specific bacteria introduced below, even at a height of eleven feet, nine inches above the liquid. Again, emulsions of *B. prodigiosus* were flushed from the closets of drainage systems in actual use and the germs thus introduced were found in all parts of the systems in open connection therewith, even at a height of fifty feet above the traps. Major Horrocks, by the same method of exposing Petri plates, found *Bacillus coli*, the characteristic organism of sewage, in a house drain and in the main sewer of the town. Finally he passed the feces of a typhoid patient suspended in water through a half-S-trap and found the typhoid organism on plates in a vertical pipe above it at a height of 3 feet, six inches above the liquid.

Major Horrocks' report, and a still more recent series of confirmatory experiments by Dr. F. W. Andrewes of London, naturally excited the deepest interest among sanitarians. In many quarters the old suspicions of sewer air were revived in almost their full force.

The Journal of the American Medical Association for example said in commenting upon Horrocks' work: "We may still have to look to sewer emanations as the occasional cause of mysterious outbreaks of disease." Other sanitarians maintained a more conservative attitude, and waited further evidence before abandoning their previous conclusions. The matter stood about as follows: On the one hand Horrocks had shown that specific bacteria, present in traps and drains, could get into the air above by splashing, by the bursting of bubbles and even in some experiments from the surface of liquids apparently in quiet motion; he detected such bacteria by the plate method in the air of ventilating pipes at considerable distances, (once at fifty feet) above the infected liquid. On the other hand, Miquel Petri, Uffelmann, Carnelley and Haldane, Laws and Andrewes and others had shown that the number of bacteria actually present in the air of sewers and house drains is extremely small and that those present are generally air forms and not sewage forms. Furthermore reliable evidence of the spread of infectious disease by sewer air is wholly lacking. The inconsistency of the two sorts of evidence required explanation; and, after presenting the facts to the Sanitary Committee, of the National Association of Master Plumbers, I was commissioned by them to attempt the clearing up of the apparent contradiction.

I first attempted to repeat as closely as possible one of Horrocks' simpler experiments. I examined the air of a boat chamber on one of the main sewers of the city of Boston, as Horrocks had done in the sewers of Gibraltar. I found colon bacilli, the characteristic sewage organism, on my plates in many experiments; but their number was least nearest the sewage, greater nearer the street, and greatest in the street air itself. It was clear that they came from street dust infected by horse dung, etc., and not from the sewage at all. I then constructed an experimental pipe system, such as Horrocks used, consisting of a half-S trap of six-inch tile drain to which an eight-foot vertical stack of the same pipe was connected. A rich emulsion of *B. prodigiosus* culture, or of *B. coli* culture, in soapy water was poured through the trap and Petri dishes of nutrient gelatin or agar were suspended at various points in the pipe above. Control plates were also exposed at various points in the laboratory outside. Six out of 28 plates exposed in the pipe over the *B. coli* emulsion showed colonies of this germ, 14 colonies in all. Eight out of 24 plates exposed in the pipe over liquid infected with *B. prodigiosus* showed this organism, 17 colonies in all. The general effect of these experiments was therefore to confirm the results of Major Horrocks. My tests, like his, showed that specific bacteria are discharged into the air from the surface of foaming infected liquids and may be carried up in connecting pipes for considerable distances. Furthermore I found that the velocity of an air current capable of transporting bacteria in the form in which they are sprayed into the air from an atomizer is very low indeed.

Granting then that infection of the air above sewage may take place, how can the results of actual examinations of sewer air be explained? The idea suggested itself at once that the whole question might be a quantitative one. It might be possible that under extreme conditions sewage bacteria get into the air but that the number discharged is so small under normal conditions that it does not appreciably affect the composition of the air of the sewer as a whole.

I next therefore attempted to investigate the question from this standpoint; and made first a careful examination of the best available quantitative methods. Horrocks' procedure of exposing open dishes of nutrient media to the air is of course not quantitative at all since the bacteria which happen to fall on the plate are not related to any particular volume of air. The method adopted by most recent observers, and the one which I used in the experiments reported a year ago, involves the straining out of the bacteria in a measured volume of air by drawing it through a sand filter. The bacteria are then washed out from the sand in sterile water and enumerated by the ordinary cultivation methods. During my work this year I developed a new method in which a measured volume of air is drawn into two large Culture Bottles and the bacteria are allowed to settle out and form colonies on nutrient media in the bottom of the bottles. This method, although cumbrous, avoids all danger of losing bacteria by drawing them through the sand and was used in all my later work. A careful series of comparative tests showed, however, that the sand method used in other investigations is essentially accurate and earlier results may be accepted as correct in their general conclusions.

By the use of the Culture Bottle Method I next attempted to control Major Horrocks' results from the quantitative standpoint. I prepared a rich emulsion of *B. prodigiosus*, containing hundreds of millions of bacteria per liter, made it foam freely by beating it up with soap, and poured it into a large glass bottle or into an open dish. The air in the bottle, or the air of the laboratory over the open dish, was examined by the Culture Bottle Method. Out of thirty liters of air examined, five only contained *B. prodigiosus*. In one liter, three were found, and in the other four, one each. Clearly the bacterial infection of the air produced by very vigorous foaming was but slight.

In these experiments there was but little splashing of the infected liquids; the bursting of bubbles from the foaming surface was the only source of air infection. I next imitated natural conditions more closely. Through the kindness of Mr. Craig I had an ordinary porcelain water-closet bowl set directly on a four-inch cast-iron S-trap, having a clean-out hole at its crown. The S-trap was connected at its lower end with an ordinary four-inch running trap. A rich, soapy emulsion of *B. prodigiosus* was poured rapidly into the water-closet bowl so as to rush down through the two traps, foaming and splashing as it went. Samples of air were collected from the clean-out at the crown of the upper trap and from the upper opening of the lower running trap, a few inches only from the foaming surface of the liquid. Everything was as favorable as possible for the discharge of bacteria into the air. Yet, out of 44 liters of air examined, 43 contained no *B. prodigiosus.* One liter showed a group of eleven colonies apparently derived from a single infected droplet. It must be remembered that in these experiments, I used liquids artificially infected with large numbers of specific bacteria and caused to foam artificially by beating them up with a considerable addition of soap. Vigorous splashing was added to foaming in the last series of tests. Under these extreme conditions, as in Major Horrocks' experiments, the specific bacteria present could be detected in the air; yet the actual number present even here was extremely small.

These experiments seemed to offer a reasonable explanation of the difference between Major Horrocks' results and those of other observers. Bacterial infection of the air from foaming liquids may take place. Horrocks, using for the most part artificially prepared emulsions and ignoring the quantitative aspect of the case, naturally obtained positive results. When the question is approached numerically, however, the amount of air infection, even under extreme conditions, is so slight that one would scarcely expect the general air of sewers and house drains to be appreciably affected under normal conditions.

The final test of experimental conclusions of this sort must always be made by an appeal to existing conditions under normal circumstances of actual use. The numerous investigations cited above have shown that the air of street sewers is indeed singularly free from bacteria. The air of house drainage systems might, however, be supposed to be worse than that of the street sewers; and with regard to their bacterial condition only the single report of Uffelmann appears to be available. As a crucial test, I therefore determined to carry out a sufficient number of examinations of house drain air to gain a fair idea of its bacterial composition. With the cordial co-operation of Mr. Craig, I have been able to complete this work and to obtain results which seem to be conclusive.

I studied nineteen different plumbing systems, five in buildings of the Massachusetts Institute of Technology, four in the wards of the Boston City Hospital, three in a block of East Boston tenements, two at the Boston City Hall, two at the Hotel Lenox and one each in the Ames Building, in the Technology Club, and in a private residence on Newbury Street. The plumbing pipes were tapped at various representative points, on the main stack in the lower part of the building, on the projection of the main stack above the roof, on clean-outs on the main house drain, on wastes from fixtures and dead ends in connection with the house drain, and in one case on the ventilation system at some distance from the main stack. From each of twenty points selected, ten liters of air were drawn off and examined for the characteristic bacteria of sewage, the colon bacillus and the sewage streptococcus.

In all, 200 liter samples of air were examined. Three samples were lost from the fact that the liquid sewage in the plumbing pipe ran into the collecting tube and over into the Culture Bottle, directly contaminating it with liquid. There remained then 197 tests. Of these 193 showed no sewage bacteria present. In the remaining four cases, sewage organisms were found, the colon bacillus three times and the streptococcus once. In each one of these four cases there was a discharge of sewage in the pipe at the point of examination, and at the moment the sample was taken so that spray was actually splashing in the air. In each of the four cases a sample of air from the same point ten minutes later showed no sewage forms present. In not a single case out of the 200 were sewage bacteria present in a liter of house drain air unless there was mechanical splashing at the point, and at the moment, of examination.

In general my results confirm the results of Horrocks in so far as they show that specific bacteria may be ejected from liquids into the air above. My tests of house drain air, like those of Carnelley and Haldane and Laws and Andrewes on sewer air, indicate that mechanical splashing may produce a local infection of the air in immediate contact with the spray. Such an infection does not, however, extend for any distance or persist for more than a minute or so. I found the general air of house drainage systems singularly free from bacterial life. Out of 200 liters examined, only 48 contained any organisms capable of development at 37°. Sewage bacteria were found in the air of the house drains only four times out of 200 liters, and then in the presence of mechanical spraying of sewage at the point of collection. The general air of the house drainage system, aside from this local infection, was, as far as examined, free from sewage organisms. These results accord well with those obtained by Miquel, Petri, Carnelley and Haldane and Laws and Andrewes in street sewers, and with those reported by Uffelmann for drain air.

The experiments of Major Horrocks, rightly interpreted, in no way contradict this general consensus of opinion. He demonstrated a possibility; by using, for the most part, artificially infected, and foaming emulsions, and by ignoring all quantitative considerations. We must deal, however, in sanitation, not with theoretical possibilities, but with probabilities, measured as closely as possible in regard to their practical importance. I have found in my experiments that even under the most extreme conditions the number of bacteria which get into the air from an infected liquid is small. I have found by the examination of a series of plumbing systems in actual use that intestinal bacteria could only be isolated four times out of 200 liters, and then only at points of direct local infection from splashing.

In a surface water of good quality, like that of New York City, the colon bacillus can almost invariably be isolated from ten cubic centimeters. This means a slight degree of intestinal pollution, but experience has shown that the chance of infection from such a water is but slight; and we drink it without serious alarm. If one were to breathe for 24 hours the undiluted air of a house drainage system, at any point not immediately infected by mechanical splashing, it appears that less than fifty intestinal bacteria would be taken in; for the daily consumption of air is about 10,000 liters, and in 200 liters I obtained negative results from air of this sort. In drinking New York water, twice as many colon bacilli are ingested every day, for 1000 cubic centimeters is a small amount for daily consumption. So there would be less danger of contracting disease from continually breathing the air of a vent pipe, or of a soil pipe, except where liquid is actually splashing, than from drinking New York water.

There is a possibility of course that the gaseous emanations from decomposing organic matter may exert a pre-disposing influence which makes the body succumb more easily to specific germs, introduced in other ways. Many have held that in this way sewer gas might indirectly promote disease. This view, supported mainly by the experiments of Alessi, well deserves further study; but I have not dealt with it in the present investigation. I believe, however, that my results, in the light of all previous evidence, warrant the conclusion that the chance of direct bacterial infection through the air of drains and sewers is so slight as to be practically negligible.

June, 1908.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 229

THE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS

WITH A CHAPTER ON THE

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS

BY

EARLE BERNARD PHELPS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

Page.

- Disinfection of sewage and sewage-filter effluents 7
  - Introduction 7
  - Sewage purification 7
    - Purifying agents 7
    - Fate of bacteria in sewage filtration 8
    - Necessity for disinfection 12
    - Methods of disinfection 15
      - Classification of methods 15
      - Heat 15
      - Lime 16
      - Acids 16
      - Ozone 17
      - Chlorine and its compounds 17
        - Germicidal action 17
        - Chlorine gas 17
        - Hypochlorites 18
          - Use in disinfection 18
          - Hamburg experiments 19
          - Berlin experiments 21
          - Experiments at Bengal, India 24
          - Experiments in Ohio 25
        - Electrolytic chlorine processes 25
          - Electrolytic manufacture of chlorine 25
          - Webster process 26
          - Woolf process—Electrozone 27
          - Hermite process 27
          - Oxychloride process 28
      - Copper and its compounds 29
      - Miscellaneous methods 32
        - Permanganates 32
        - "Amines" process 32
        - Sodium benzoate and other organic compounds 33
      - Summary of disinfection methods 33
- Experimental investigations 34
  - History 34
  - Bacteriologic methods and expression of results 35
  - Investigations at Boston 37
    - Scope and character of experiments 37
    - Preliminary experiments with chloride of lime 38
    - Disinfection of trickling-filter effluent 39
    - Disinfection of crude sewage 46
  - Disinfection of septic sewage at Red Bank, N. J 51
  - Disinfection of trickling-filter effluent at Baltimore, Md 56
  - Comparative germicidal efficiencies of chlorine and some of its compounds 60
  - Effect of calcium *hypochlorite* on colon and typhoid bacilli 62

P

Disinfection of sewage and sewage-filter effluents—Continued.
- **Practical applications and costs of disinfection**
- **Conclusion**

Putrescibility and stability of sewage-filter effluents
- **Introduction**
- **Putrescibility**
- **Relative stability**
  - **Definitions**
  - **Estimation of reducing time**
  - **Theoretical relation between reducing time and relative stability**
  - **Determination**
    - **Incubation periods**
    - **Effect of temperature on reducing time**
    - **Summary of method**
  - **Interpretation of results**

DISINFECTION TABLES.

TABLE 1. Bacteria in sewage and in effluents of sewage filters at Boston in 1904.
2. Bacteria in sewage, septic effluent, and trickling-filter effluents at Boston in 1906
3. Disinfection of three crude hospital sewages with chloride of lime
4. Disinfection of the crude screened sewage of Eppendorfer, Germany, by chloride of lime
5. Disinfection of crude Berlin sewage with chloride of lime
6. Destruction by chloride of lime of *B. coli* embedded in gelatine
7. Disinfection of septic sewage by chloride of lime at Bengal, India
8. Disinfection of effluents with chloride of lime at Lancaster and Marion, Ohio
9. Analyses of London sewage before and after treatment by the Webster process
10. Summary of Rideal's experiments on the use of oxychloride at Guilford, England
11. Disinfection of trickling-filter effluents with copper sulphate at Columbus, Ohio
12. Disinfection of sewage and effluents with copper sulphate at Columbus, Ohio
13. Effect of organic matter and of alkalinity on the germicidal properties of copper sulphate
14. Disinfection of trickling-filter effluent with copper sulphate at Boston
15. Disinfection of effluents with copper sulphate in Ohio
16. Chemical analysis of trickling-filter effluent at Boston before and after disinfection with chloride of lime and sedimentation
17. Disinfection of trickling-filter effluent with chloride of lime at Boston; weekly averages
18. Disinfection of trickling-filter effluent at Boston; summary of bacteriological results averaged by periods to show the effect of changes in temperature and in the amount of available chlorine
19. Relation between individual tests of bacterial removal and the average re

Page.
TABLE 20. Relation between individual bacterial counts and the average result at Boston.......... 44
21. Relation between time of contact and efficiency of disinfection with chloride of lime.......... 45
22. Disinfection of crude sewage with chloride of lime at Boston; series 1 and 2.......... 48
23. Disinfection of crude sewage with chloride of lime at Boston; series 3. 49
24. Disinfection of crude sewage with chloride of lime at Boston; summary of results.......... 50
25. Disinfection of septic sewage with chloride of lime at Red Bank, N. J.; weekly averages.......... 54
26. Relation between individual tests of bacterial removal and the average result at Red Bank, N. J.......... 55
27. Chemical analyses of trickling-filter effluent at Baltimore, before and after disinfection with chloride of lime and sedimentation... 57
28. Disinfection of trickling-filter effluent with chloride of lime at Baltimore; weekly averages.......... 58
29. Relation between individual tests of bacterial removal and the average result at Baltimore.......... 58
30. Relation between individual bacterial counts and the average result at Baltimore.......... 59
31. Average bacterial removal during the disinfection of trickling-filter effluent at Baltimore.......... 59
32. Relative germicidal properties of chlorine and some of its compounds 60
33. Comparative resistance to calcium hypochlorite of *B. typhi* and *B. coli* in aqueous emulsion.......... 63
34. Estimates of the cost of maintenance and operation of a plant for disinfecting sewage or effluent with chloride of lime; based on a capacity of 5,000,000 gallons a day.......... 66

RELATIVE STABILITY TABLES.

ABLE 1. Relation between reducing time and relative stability at 20° centigrade.......... 82
2. Summary of stability tests of trickling-filter effluents, showing time required to exhaust the available oxygen.......... 84
3. Comparison of relative stability results obtained from the twenty-day incubation period shown in Table 2 with those calculated from a four-day period.......... 85
4. Comparison of relative stability results obtained from smaller numbers of samples by the use of four, six, and twenty day incubation periods.......... 85
5. Relation between relative stability and reducing time at 20° and at 37° centigrade.......... 87

ILLUSTRATION.

ATE 1. *Plan of sewage-disposal works* at Red Bank, N. J.......... 52

THE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS.

By Earle Bernard Phelps.

INTRODUCTION.

The investigations on which this report is based were conducted by E. B. Phelps at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology at Boston, Mass., and, in collaboration with Mr. Phelps, by Francis E. Daniels at the sewage-disposal works at Red Bank, N. J., and by Ezra B. Whitman at the Walbrook Testing Plant at Baltimore, Md., under cooperative agreements with the Massachusetts Institute of Technology, the State Sewerage Commission of New Jersey, and the city Sewerage Commission of Baltimore.

SEWAGE PURIFICATION.

PURIFYING AGENTS.

The essential agents of sewage purification are provided and employed by nature. The slow action of the soil bacteria, aided by atmospheric oxygen, eventually converts into harmless mineral ingredients all organic matter that comes within its sphere of activity, the process being analogous to that of combustion. Sewage purification as practiced to-day is but the intensive application of these natural processes under controllable conditions. The improvements that have been made in methods of treating sewage have not involved the discovery or application of new principles, but have merely increased the working efficiency of the natural bacterial agencies. The constant aim of the experimenters has been to increase the rate at which sewage can be treated on a given area of land. From the old-time sewage irrigation field, with its maximum capacity of possibly 10,000 gallons an acre in twenty-four hours, to the present-day trickling filter capable of dealing with two or three million gallons an acre a day, the march of improvement has been steady and *continuous*. The amount of sewage that can be purified on an acre of filtering area has been increased two or three hundred fold, and investigators are working toward a still greater increase.

It must be admitted that the significance of the word "purify" has also undergone a radical change. The effluents are no longer pure ground water. The liquid flowing from a modern trickling filter looks to the untrained eye like the original sewage. The organic matter of the sewage is no longer "burned up" to harmless mineral matter; indeed, there is almost as much organic matter in the effluent as in the raw sewage, and sometimes more. What change then has taken place to justify the use of the term "purified?" The answer lies in the fact that the organic matter has been changed but not removed. To carry out the simile, the organic matter, though not burned, has been charred or partly oxidized, and this charring process has been sufficient to rob it of its putrescibility or foulness. In other words, its chemical composition has been so altered that it is no longer capable of undergoing rapid putrefactive decomposition.

On first consideration it appears inconceivable that the chief object of sewage disposal—prevention of the fouling of streams—could be attained by such subtle changes in the nature of the organic matter. Nevertheless, effluents containing comparatively large amounts of organic matter may be discharged into streams without fear of causing nuisances if the organic matter is nonputrescible and if conditions preclude immediate sedimentation. The work of purification proceeds in the stream as it does in the soil until the oxidation, or combustion, is complete, oxygen for that purpose being sufficiently abundant in a reasonably clean stream. On the other hand, too much crude sewage added to water first robs it of all its available oxygen, then, in the anaërobic condition thus established, kills the beneficent oxidizing bacteria and transforms the stream practically to an open sewer. It is apparent, therefore, that purification of sewage has come to mean primarily the removal of its tendency to putrefy and not the total oxidation and removal of all its organic matter.

FATE OF BACTERIA IN SEWAGE FILTRATION.

In the older and more perfect methods of sewage purification the bacteria of the sewage with the other organic matter were destroyed by the straining action of the soil and the oxidizing action of the normal soil bacteria; but a modern filter of coarse stones neither strains the material nor affords opportunity for vigorous oxidation. Much of the original organic matter passes through such a filter, having undergone changes so slight as almost to defy detection by ordinary chemical means. It is reasonable, therefore, to inquire as to the fate of the sewage bacteria and particularly as to the pathogens, or disease-producing The data on this point are somewhat conflicting. The question was raised in 1893 in connection with the first septic tank at Exeter, England. The fear was expressed that pathogenic germs might even multiply in the tank, as other forms of bacteria are known to do. Sims Woodhead conducted an investigation as a result of which he concluded that no organisms capable of setting up morbid changes in animals after inoculation came from the tank. Pickard introduced an emulsion of typhoid bacilli into the Exeter tank and observed a slow diminution in number. It is important to note, however, that even after fourteen days 1 per cent of the original number was still alive. Pickard also reported a removal of over 90 per cent of the typhoid organisms introduced into a contact filter. Rideal, on examining the effluents of three Scott-Moncrieff filters at Caterham, England, found reductions in *Bacillus coli* ranging from 95 per cent to 98.5 per cent. He made the following statement before the Royal Sewage Commission:[a] "Satisfactory evidence in most of the systems is now available from which I think we are justified in concluding that even if towns on a river like the Thames adopted bacterial schemes the pathogenicity of the London water supply would not be adversely affected thereby."

On the other hand, there is some evidence that the pathogenic properties of sewage are not materially altered in its passage through a coarse-grained filter. Alfred MacConkey[b] made a series of tests upon the longevity of *B. typhi* in various waters. Samples of the liquid under examination were inoculated with large numbers of typhoid bacilli and were kept under observation. In one experiment the organism was isolated from sewage thirteen days after inoculation. In a second set of two tests it was not found after fifteen and after seventeen days. In two contact-bed effluents it was found after fifteen and seventeen days, respectively, while in two other contact-bed effluents it did not survive beyond the sixth day. MacConkey concluded that the numbers of typhoid organisms reaching a filter are ordinarily so small that there is but slight possibility of their passing through, but "if from any cause they arrive to the tanks in such large numbers as the *B. coli*, then certainly they might appear in the effluent just as the *B. coli* does." In interpreting such results due allowance must be made for the fact that the isolation and identification of the typhoid bacillus under such conditions is extremely difficult and that failure to detect the organism carries much less experimental weight than a positive result.

Houston,[c] in a careful investigation of the subject for the Royal Sewage Commission, found that the effluents from septic tanks, contact beds, and trickling-filter beds contained enormous numbers of bacteria. In some of the tests the per cent reduction in the effluents as compared with the raw sewage was striking; but as it was necessary to judge an effluent by its actual condition, and as the number of micro organisms still remaining was almost always very large, he concluded that per cent purification is of minor importance. In not a few of the tests the bacteria were practically as numerous in the effluent as in the raw sewage. The relative abundance of the different kinds of bacteria appeared to be much the same in the effluents as in the crude sewage. Of undesirable bacteria, such as *B. coli*, proteus-like germs, spores of *B. enteritidis sporogenes*, and streptococci, the effluents contained nearly as many as the crude sewage. The reduction in numbers of these objectionable bacteria was apperently not marked enough to be of consequence from the point of view of the epidemiologist. No definite proof was found that the effluents from bacterial beds were conspicuously safer than crude sewage in their possible relation to disease. Attention was especially called to the presence of streptococci in the effluent. Houston contends that if it be true that streptococci are more delicate germs than the typhoid bacillus, their presence in large numbers in the effluent indicates the possibility or probability that the typhoid bacillus also survives under similar conditions—a view that leads to the inference that the biological processes at work are not strongly inimical, if hostile at all, to the vitality of pathogenic germs. Experiments with *B. sporogenes*, a spore-forming organism, have shown that it passes through filters in almost undiminished numbers.

---

[a] Interim Rept. Royal Sewage Commission, 1901, Question No. 4148, p. 251.

[b] Second Rept. Royal Sewage Commission, 1902, p. 62.

[c] Houston, A. C., Second Rept. Royal Sewage Commission, 1903, p. 26.

Besides the facts already mentioned, little information is available which bears directly on the fate of the pathogens, and particularly of the typhoid organism, in sewage purification. It is therefore necessary to examine the available indirect evidence. By studying the removal of certain specific organisms that are easily detected and certain well defined groups of organisms existing in sewage, the probability of the elimination of the typhoid organism can be determined. In the absence of further data it must be assumed for the sake of safety that the elimination of the typhoid bacillus is not materially greater than that of the other species and groups that may be studied. During the summer of 1904 there were operated at the sewage experiment station four septic tanks running at storage periods of from twelve to forty-eight hours, nine contact beds differing in material, depth, and rate, three trickling filters, and three sand filters, one of each set being run with crude sewage and two kinds of septic effluents, respectively. The results of bacterial counts are shown in Table 1, in which the numbers are averages of all results obtained with one kind of filter.[a]

---

[a] Winslow, C. E. A., The number of bacteria in sewage and sewage effluents: Jour. Infect. Dis., vol. 1. *Suppl. 1, 1905, p. 200.*

TABLE 1.—*Bacteria in sewage and in effluents of sewage filters at Boston in 1904.*

[Winslow.]

Source of sample.	Number of examinations.	Bacteria per cubic centimeter.					
		Lactose gelatin at 20° C.			Lactose agar at 37° C.		Anaërobic agar.
		Liquefiers.	Acid formers.	Total.	Acid formers.	Total.	
Sewage	56	365,000	1,670,000	5,430,000	1,670,000	3,760,000	2,440,000
Septic effluent	56	162,000	495,000	1,750,000	650,000	1,040,000	930,000
Contact filters	140	60,000	270,000	1,060,000	290,000	570,000	440,000
Trickling filters	18	134,000	114,000	451,000	284,000	1,170,000	200,000
Sand filters	15	500	1,360	9,160	11,400	43,600	1,200

The septic tank and two trickling filters in operation at the same station during the summer of 1906 gave the average results recorded in Table 2, showing that less than one-half of the bacteria growing at 37° C. were removed by filtration, and that the reduction in the number of colon bacilli was practically in the same proportion.

TABLE 2.—*Bacteria in sewage, septic effluent, and trickling-filter effluents at Boston in 1906.*

Source of sample.	Bacteria per cubic centimeter; lactose agar at 37° C.	B. coli; positive[a] tests in one-millionth of a cubic centimeter.
		Per cent.
Sewage	1,300,000	65
Trickling filter receiving sewage	730,000	35
Septic effluent	1,650,000	66
Trickling filter receiving septic effluent	750,000	35

[a] The bile broth presumptive test recommended by D. D. Jackson was employed.

Johnson,[a] in his experiments at Columbus, found a reduction in the total number of bacteria ranging from 33 per cent to 60 per cent in primary-contact filters, and a removal of about 39 per cent of the remainder in secondary-contact filters, and from 30 per cent to 80 per cent in trickling filters, depending largely on the depth of the filter. Subsequent sedimentation increased this removal to 87 per cent. Thumm and Pritzkow,[b] at Berlin, report a reduction in the number of bacteria from 17,000,000 in the sewage to 6,000,000 in the effluent of a double-contact filter. At La Madelein, France, Calmette[c] found 5,000,000 bacteria per cubic centimeter in crude sewage, 2,900,000 in a secondary-contact effluent, and 800,000 in the effluent from a trickling filter. The sewage contained 20,000, the contact effluent 4,000, and the trickling effluent 2,000 colon bacilli. At Plainfield, N. J., the double-contact filter was found to reduce the number of bacteria from an average of 1,000,000 per cubic centimeter to an average of 322,000; *B. coli* ranged from 1,000,000 to 100,000 in the sewage and from 100,000 to 10,000 in the effluent.[a] An experiment performed by Houston[b] is important in this connection: *B. pyocyaneus*, a pathogenic organism, was applied to the top of a trickling filter, and ten minutes later the bacillus appeared in the effluent, continuing to be discharged for ten days. In a similar manner the same organism was found to pass through a septic tank and a contact filter successively, and to persist in both for nine days. At Baltimore, Md., the board of advisory engineers concluded that 95 per cent of the bacteria in the sewage could be removed by a system comprising a septic tank, 9-foot trickling filters, and supplementary sedimentation basins.[c] Such results are better than those usually obtained elsewhere, and if they can be maintained in practice they will go far toward solving the problem in that locality.

---

[a] Johnson, Geo. A., Report on sewage purification at Columbus, Ohio, 1905.

[b] Thumm, K., and Pritzkow, A., Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, 1903, vol. 2, p. 127.

[c] Calmette, A., Recherches sur l'epuration des eaux d'égout, Lille, 1907, vol. 2.

From a consideration of the available evidence it may be stated in a general way that coarse-grained, rapid sewage filters remove a considerable proportion of the sewage bacteria; that such removal has not been found to be sufficiently complete in practice to have great sanitary significance; that bacteria of various groups and certain specific organisms pass through such filters in practically the same proportions as the bacteria as a whole; and that, in the absence of any information to the contrary, it should be assumed that such filters have no greater effect on the typhoid and other pathogenic organisms than on *B. coli*, *B. pyocyaneus*, sewage streptococci, or the different groups of sewage bacteria.

THE NECESSITY FOR DISINFECTION.

It is probable that removal of bacteria will again be considered an essential factor in sewage purification. That it was so considered formerly is well known. The development of the modern rapid filter has made it possible to introduce sewage purification under conditions where it would have been impossible or prohibitively expensive in former days. In the acceptance of a partial solution of the problem much has been gained and but little lost. The process of purification that renders practically stable the offensive organic matter of sewage has accomplished the most important and in many cases the only essential requirement. If, however, sewage effluents find their way into the drinking waters of neighboring communities, the question of the relative responsibility of the settlements is debatable. It is generally conceded at present that efficient sewage purification should be undertaken by the communities in which the sewage originates, and that purification of the water supply is the urgent duty of the other communities. As streams flowing through populous districts are necessarily contaminated and unfit for domestic use without filtration, it is considered unjust to require a community to purify its sewage to a higher degree bacterially than that shown by the stream into which it is discharged. On the other hand, in the fight against infectious diseases, sound tactics demand an attack on the enemy as near as possible to the initial source of infection. The best and easiest place to destroy typhoid germs is at the bedside of the typhoid patient; but this method can not be relied on to keep sewage free from infection, and the next strategic point is certainly the sewage. Once at large the germs may reach their victims in a score of well-known ways, and who will say by how many devious and unknown paths? With increasing knowledge of these facts and with improved processes and reduced cost of disinfection it is not too much to expect that the disinfection of sewage will some day be regarded as an integral part of its purification and as a necessary measure of protection for the community.

---

[a] Rept. Sewerage Commission of New Jersey for 1906.

[b] Houston, A. C., Fourth Interim Rept. Royal Sewage Commission, 1904, vol. 3, p. 77.

[c] *Report of the Board of* Ad[illegible] Engineers to the Sewerage Commission of Baltimore, 1906.

One of the ways by which typhoid germs pass from the sewer to the victim is by means of shellfish fed or fattened in polluted water, and many of the oyster and clam beds of the eastern seaboard are subject to pollution by sewage. In England conditions are so serious that the demand for shellfish has perceptibly decreased. The situation presents obvious difficulties. The water of a polluted river may be rendered potable through filtration, but the purification of shellfish seems to be out of the question; it follows, therefore, that health must be safeguarded either by preventing the discharge of the bacteria of sewage on shellfish beds or by prohibiting the taking of the shellfish. In a large community where the shellfish industry is small it will probably be more satisfactory to adopt the latter method, but in small communities whose sewage pollutes large and important beds thorough bacterial purification is not an unreasonable requirement. Unfortunately the greatest shellfish areas of the country are situated near large cities, where they are subject directly or indirectly to possible pollution from sewage discharge.

In a carefully prepared paper on the pollution of shellfish beds, G. W. Fuller[a] states that the annual crop of oysters gathered along the Atlantic and Gulf coasts in 1902 amounted to more than 25,000,000 bushels, exceeding in value $13,000,000, and that the crop of clams was more than 2,000,000 bushels, valued at $2,000,000. Over one-half of this total production came from New Jersey, Maryland, and Virginia, and the shellfish were grown mainly in the waters of Delaware and Chesapeake bays, which receive the sewage from many large cities. At present this sewage is so enormously diluted by the bay waters that the danger of pollution is in most places remote, but it is present and ever increasing.

---

[a] Concerning sewage disposal from the standpoint of the pollution of oysters and other shellfish, with special reference to their transmission of typhoid fever: Jour. Franklin Inst., vol. 160, 1905, p. 82.

In Baltimore a system of sewerage and sewage disposal is being planned to remedy the already serious pollution of Patapsco River. In calling on a commission of experts for advice the sewerage commission of Baltimore specified "that the effluent proposed to be discharged into Chesapeake Bay or its tributaries in the system to be recommended by the engineers shall be of the highest practicable degree of purity." [a]

By agreement between the States of New Jersey and Pennsylvania the condition of Delaware River has been thoroughly investigated, and the pollution of that stream by sewage from Trenton, Bordentown, and other smaller communities in New Jersey, and Philadelphia, Easton, and other Pennsylvania cities, is prohibited after certain specified dates.[b] The necessity for protecting these valuable shellfish beds makes bacterial removal an essential feature in any scheme of sewage disposal which may be considered for such places.

The board of advisory engineers at Baltimore recommended that the settled trickling-filter effluent be given a final treatment on sand filters. The cost of works for the complete treatment of 75,000,000 gallons of sewage a day by septic tanks, trickling filters, sedimentation basins, and sand filters was estimated at $3,283,250, of which sum $1,040,750, or over 31 per cent, was for supplementary treatment. The annual cost of operation is expected to be $115,500, of which $55,000, or 48 per cent, is for supplementary treatment. This gives some idea of the cost of complete bacterial removal by filtration processes over and above the cost of reasonable organic purification. In regard to disinfection by chemical means the advisory engineers state: "To remove all bacteria remaining in the settled effluent from the sprinkling filters by disinfectants, such as hypochlorite of lime or of sodium or sulphate of copper, would be prohibitively expensive"—an authoritative opinion based on the best evidence then to be had. Almost no American data on chemical disinfection were available, and the results of experiments in Germany indicated that such disinfection could be accomplished only at high cost. The patented processes mainly used in England were also expensive. It was therefore desirable to learn just how effective disinfection processes could be made under conditions in America—how much they would cost, and what after effects, objectionable or otherwise, might follow their introduction.

---

[a] *Report of the Board of Advisory Engineers to the Sewerage Commission of Baltimore, 1906.*

[b] *Rept.* New Jersey State Sew[illegible]ission, 1907.

A review of the available data and a short experimental investigation made in 1906 at Boston[a] led the writer to believe that there is much value in the process and that it might afford the best possible solution of the whole problem under certain conditions common in this country, particularly in localities where the shellfish question is involved.

METHODS OF DISINFECTION.

CLASSIFICATION OF METHODS.

In Great Britain the somewhat indefinite allusions of the royal sewage commission to sterilization as a finishing process in sewage treatment aroused a storm of discussion that resulted, at least, in clearing away many misconceptions. Sterilization processes of many kinds have been investigated, and the subject has been freely discussed. For the following classification of sterilizing agents and for many of the facts noted here the writer is indebted to Rideal,[b] whose carefully prepared paper on the subject discusses its possibilities in a thoroughly impartial manner. Other authorities are cited wherever possible. Except when otherwise stated, costs are based on current prices in eastern markets.

The different methods and substances proposed for the sterilization of effluents are considered in the following order:

1. Heat.
2. Lime.
3. Acids.
4. Ozone.
5. Chlorine and its compounds.
    - (a) Chlorine gas.
    - (b) Hypochlorites, or oxychlorides.
    - (c) Electrolytic chlorine processes.
6. Copper and its compounds.
7. Miscellaneous.
    - (a) Permanganates.
    - (b) "Amines" process.
    - (c) Sodium benzoate and other organic compounds.

HEAT.

The use of heat has been suggested for disinfecting sewage. In his testimony before the royal sewage commission E. E. Klein[c] referred to a patented process which he considered practicable, by the use of which sufficient ammonia could be recovered from the sewage nearly to pay for the treatment; but there is no record that this process has ever been used on a working scale. A device for heat interchange, similar to that employed in the Forbes sterilizer may possibly, as is claimed, raise water to the boiling point and cool it again within 5° F. of the initial temperature. With coal at $3 per ton having a calorific value of 10,000 British thermal units, the fuel cost alone of such an operation would be about $7 per million gallons of sewage. The ammonia in a million gallons of Boston sewage, if in the form of sulphate, would have a market value of $20. Whether the difference between the value of the ammonium sulphate and the cost of the fuel is sufficient to cover the cost of operation, including labor, evaporation of the dilute solution, and all fixed charges can be determined only by actual experiment, but the plan is not wholly without possibilities.

---

[a] Phelps, Earle B., and Carpenter, William T., The sterilization of sewage-filter effluents: Tech. Quart., vol. 19, 1906, p. 382; Contributions from the Sanitary Research Laboratory, vol. 4, 1908.

[b] Rideal, S., On the sterilization of effluents: Jour. Royal Sanitary Institute, vol. 25, p. 378.

[c] Interim Rept. Royal Sewage Commission, 1901, question 9674, p. 519.

LIME.

Caustic lime acts only slightly as a germicide, and the considerable removal of bacteria that takes place when lime is used as a precipitant in sewage is undoubtedly due to the action of the precipitate itself in dragging down with it the bacteria which it has entangled. Such action occurs to some extent in the precipitation of any substance, and even the sedimentation of sewage is always accompanied by reduction in the numbers of bacteria. Lime alone, therefore, would be of little value for sterilizing effluents. Rideal states that 60 to 70 grains per imperial gallon (860 to 1,000 parts per million) are inefficient in sterilization. Thresh, however, believes that lime would produce a satisfactory sterilization of effluents.[a]

ACIDS.

Most bacteria, and particularly typhoid and cholera germs, are more readily destroyed by acids than by alkalies. Rideal, therefore, considers it feasible to employ acids as germicides. He states that Stutzer found 0.05 per cent acid solutions fatal to bacteria in twenty-four hours; that Ivanoff found that 0.04 per cent to 0.08 per cent of acid destroyed the cholera germs in the sewage of Berlin and of Potsdam; that Kitasato found 0.08 per cent of sulphuric acid fatal to typhoid bacilli in fifteen minutes, and that he had himself obtained similar results. To furnish 1,000,000 gallons of sewage with 0.08 per cent of sulphuric acid requires 6,650 pounds of acid, costing approximately $73. Smaller amounts of acid might be used, as it would be unnecessary to kill typhoid germs in so short a time as fifteen minutes; but, on the other hand, most sewage contains a considerable amount of free alkali which must be neutralized before any germicidal effect of the acid would be obtained. This process consequently would seem to be impracticable except in emergencies. It is interesting to note that the sewage of Worcester, Mass., contains normally an average of 0.01 per cent of free sulphuric acid, or half enough to kill cholera germs in twenty-four hours.

---

[a] Interim Rept. Royal Sewage Commission, 1901, question 8917, p. 502.

OZONE.

Ozone has been used more or less successfully in Germany, particularly at Weisbaden, for sterilizing drinking water. Though the process has been most favorably commented on by those in immediate charge of the investigations, it has not been generally regarded as successful. The possibility of procuring a satisfactory effluent by this process, when the water is that of a highly-polluted river is beyond question, but whether the process can satisfactorily treat a sewage effluent of considerable turbidity has not been determined. Rideal calls attention to the fact that ozone is but sparingly soluble in water, and on that account it might fail to penetrate the solid masses in the effluent, since the rate at which a dissolved gas will penetrate solids in a liquid is a direct function of its solubility. The principal cause of failure of the ozone process, however, seems to be its expense. If this be true in waterworks it is hardly possible that such treatment could be applied to sewage effluents as an additional safeguard after purification. Data are not at hand for estimating the cost of applying ozone treatment to sewage effluents, but besides the cost of operation there is the very considerable cost of installing the necessary machinery and towers.

CHLORINE AND ITS COMPOUNDS.

GERMICIDAL ACTION.

Chlorine is well known as a powerful germicide. As a bleaching agent it acts on organic coloring matter indirectly by means of the free nascent oxygen which it liberates from the water in which it is dissolved, and it is probable that its germicidal action is similar. In other words, chlorine and ozone owe their germicidal power to the same thing—nascent oxygen. Chlorine, however, has the advantages of being cheap, of being more readily soluble, and of being obtainable in compounds that are easily transported and handled.

CHLORINE GAS.

Until within a few years chlorine has been manufactured commercially by the Weldon or some similar process. In the Weldon process hydrochloric acid is made to react with a complex mixture of manganese hydroxide and lime—"Weldon mud"—the reaction bein essentially

$$MnO_2+4HCl=MnCl_2+2H_2O+Cl_2,$$

though in reality it is much more complex. Recently, howeve electrolytic processes have been developed, by which the cost o manufacture has been materially reduced, particularly where chea water power is available. Chlorine prepared by the mixing of common salt, an acid, and a suitable oxidizing agent was used in Englan as early as 1800 by Cruikshank, who recommended manganes dioxide and potassium bichromate as oxidizing agents. The objections to the use of gaseous chlorine are chiefly the cost of transportation, the difficulty and danger of handling the gas, and the difficult of measuring accurately the amount of gas added to the effluent Furthermore, in disinfection free chlorine is not so efficient as th hypochlorite.

Available chlorine, a term frequently used in the discussion o chlorine disinfection methods, is determined by titrating a solutio with arsenious acid, or with some other reducing agent, and it represents in reality the oxidizing power of the substance expressed in terms of chlorine. For example, hypochlorous acid in the presence of a reducing agent is decomposed according to the following equation:

$$HClO=HCl+O.$$

The oxidizing power of this acid, or the available chlorine, is, therefore, two hydrogen equivalents per molecule, which is twice its total chlorine content, a fact that makes the term available chlorine a misnomer, but it has come into general use in the chlorine industries and it is a convenient expression. In this article it signifies oxidizing power, determined against arsenious acid, and expressed in terms of chlorine.

HYPOCHLORITES.

Use in disinfection.—Chlorine is handled commercially in the form of bleaching powder, or chloride of lime—an impure product composed largely of calcium hypochlorite. Bleaching powder or "bleach" containing from 35 per cent to 40 per cent of available chlorine can be obtained in the market. The hypochlorite dissolves in water, leaving a residue composed chiefly of calcium hydrate and calcium carbonate. Hypochlorites in general are made by adding chlorine to caustic alkalies. Bleaching powder is made by passing dry chlorine gas over freshly-slaked lime. It is manufactured in this country in large amounts, the chlorine being obtained by the electrolysis of salt. Abroad the chlorine is made by the older methods, and much foreign bleach is sold in this country in competition with the electrolytic product. "Eau de Javelle" and "Labarraque's solution" are solutions of sodium hypochlorite. "Chloros," a commercial preparation of sodium hypochlorite, contains 10 per cent by weight of available chlorine.

Hypochlorites have long been recognized as powerful and efficient disinfectants. The sodium and potassium compounds have not been generally used on a large scale because of their relatively high cost and the difficulty of preparing and keeping them in the dry state, but calcium hypochlorite has been extensively employed. The first Royal Sewage Commission of Great Britain used it in deodorizing London sewage in 1854.[a] The committee of 1885 of the American Public Health Association found it to be the best disinfectant available, cost and efficiency considered. It was used by Dibdin[b] in 1884 to deodorize the sewage of London, but it was not successful for that purpose and was later abandoned in favor of sodium permanganate. Its action on specific bacteria was studied by Nissen[c] in 1890. The use of bleaching powder as a sewage disinfectant has been more extensively studied in Germany than elsewhere. At the Hygienic Institute of Hamburg investigations have been made by Proskauer and Elsner, Dunbar and Zirn, Dunbar and Korn, Schumacher, and Schwarz. At the Royal Testing Station in Berlin, Kranepuhl and O. Kurpjuweit have each reported investigations.

Hamburg experiments.—Proskauer and Elsner[d] experimented at Hamburg with sewage which had been clarified by the Rothe-Degener system. They obtained satisfactory disinfection with chloride of lime, using concentrations of chlorine ranging from 2.7 to 4.0 parts per million, and ten minutes exposure sufficed practically to eliminate *B. coli.* Dunbar and Zirn[d] treated crude sewage and, in common with later workers, they imposed much more exacting standards of disinfection and used much greater concentrations of chlorine. After having employed cholera germs as test organisms, they concluded that the satisfactory disinfection of crude Hamburg sewage would require 25 parts per million of available chlorine and an exposure of two hours. Dunbar and Korn[e] studied the disinfection of crude sewage with special reference to its subsequent purification on biological filters. Schumacher[f] investigated the problem of disinfecting hospital sewages that had not received any previous treatment. In a preliminary set of bottle experiments he obtained the following results with the sewages of three hospitals.

---

[a] Second Rept. Royal Sewage Commission, London, 1861.

[b] Dibdin, W. J., Jour. Assoc. Eng. Soc., vol. 40, 1908, p. 310.

[c] Zeit. Hyg., vol. 8, 1890, p. 62.

[d] Vierteljahrsschr. ger. Med., vol. 16, 1898, Suppl. Heft.

[e] Ges. Ing., vol. 27, 1904.

[f] Idem, 1905.

TABLE 3.—*Disinfection of three crude hospital sewages with chloride of lime.*

[Schumacher.]

Concentration of chloride of lime.	Hours of contact.	Bacteria per cubic centimeter.		
		Initial content: 23,000,000.	Initial content: 37,000,000.	Initial content: 21,[illegible]
		After treatment.	After treatment.	After treatment.
1 : 7,000	2	540	200	8,4[illegible]
	4	140	260	[illegible]
	6	200	100	[illegible]
	24	160	20	[illegible]
1 : 5,000	2	60	60	[illegible]
	4	160	40	[illegible]
	6	120	....	[illegible]
	24	30	....	....
1 : 2,000	2	80	420	[illegible]
	4	20	....	[illegible]
	6	20	20	[illegible]
1 : 1,000	2	60	20	[illegible]
	4	120	40	[illegible]
	6	40	40	....

The amount of available chlorine in the chloride of lime used in these experiments is not stated, but it was probably not far from 30 per cent. On that assumption the concentration of available chlorine in the four sets of tests would be 43, 60, 150, and 300 parts per million, respectively. The high initial numbers indicate a very strong sewage. It is also worthy of note that the reduction in the number of bacteria with only 43 parts of chlorine is much greater than would be demanded in ordinary practice. Disinfection on a large scale was also conducted by the same investigator at two hospitals. After a storage period of two hours samples of one liter each were tested for *B. coli.* With a concentration of 1 : 2,000, or about 150 parts per million of available chlorine, *B. coli* was isolated from a liter of water in only 6 samples out of 43, not being found in 88 per cent of the samples tested. With chloride of lime in the proportion of 1 : 5,000, or about 60 parts per million of available chlorine, *B. coli* was destroyed in 62 per cent of the samples in two hours and in 64 per cent of the samples in four hours. Schwarz [a] called attention to the fact that excessive amounts of disinfectant are necessary on account of the large floating particles, a point previously commented on by Schumacher. Schwarz proposed, therefore, that all sewage should be carefully screened before disinfection in order to remove particles exceeding three millimeters in diameter. The screening of hospital sewage should be even more complete, removing particles exceeding one millimeter in diameter.

---

[a] Ges. Ing., vol. 29, 1906, p. 773.

During experiments at the Eppendorfer purification works, a sewage flow of about 60,000 United States gallons a day was available, and a tank holding about four hours' flow was used. As information was especially desired regarding the effect of the treatment on the cholera vibrio, an emulsion of another vibrio (Leuchtvibrionen) was added to the sewage at a regular rate before treatment, after it had been determined that this test organism would not only pass through the tank but would persist for days in the filters. Table 4 summarizes the results.

TABLE 4.—*Disinfection of the crude screened sewage of Eppendorfer, Germany, with chloride of lime.*

[Schwarz.]

Concentration of chloride of lime.[a]	Tests for vibrio in 1 cubic centimeter amounts.		Test for B. coli in 1 cubic centimeter amounts.		Final number of bacteria per cubic centimeter.[b]
	Total number of tests.	Number of positive tests.	Total number of tests.	Number of positive tests.	
1:2,000			17	0	15
1:5,000	51	0	51	1	23
1:10,000	28	0	7	0	36
1:20,000	15	0	6	0	72
1:30,000	10	0			3,620
1:40,000	8	4			59,000
Control					950,000

[a] 1:10,000 is about 30 parts per million of available chlorine, assuming that the chloride of lime contained 30 per cent of available chlorine.

[b] Initial number of bacteria per cubic centimeter, 1,320,000.

It was noted that a concentration of chloride of lime of 1: 2,000 materially affected the subsequent treatment of the disinfected sewage in trickling filters. Oxygen consumed and ammonia in the effluent were higher and nitrates lower than normal. An interesting fact noted was the production of chlorates in the filter, over 10 parts per million being recorded at one time. Schwarz concluded that sewage can be satisfactorily disinfected with chloride of lime after having been carefully passed through one millimeter mesh screens. One part in 5,000 (60 parts per million of available chlorine) was considered necessary for the destruction of typhoid germs and from one part in 7,000 to one part in 10,000 (30 to 40 parts of available chlorine) for cholera vibrio. The disinfected sewage can be subsequently purified without previous neutralization of the disinfectant.

Berlin experiments.—At the royal testing station in Berlin the subject of sewage disinfection has been studied by Kranepuhl[a] and by Kurpjuweit.[b] Kranepuhl undertook to determine the concentration of chloride of lime and the time of contact necessary to destroy the colon bacilli in crude Berlin sewage. These bacilli numbered about 100,000 per cubic centimeter. They were considered an index of the pathogenicity of the sewage, because they are more numerous and more resistant than the pathogenic forms. The bleaching powder employed contained available chlorine ranging from 25 to 35 per cent. One liter samples of sewage were treated with the desired amounts of chloride of lime, and at the expiration of the specified time the remaining available chlorine was determined and was then neutralized with sterile sodium thiosulphate. Nutrient broth was then added to the entire liter sample, after which the sample was incubated. *B. coli* was sought in the incubated sample by the usual means, and confirmatory tests for it were made.

---

[a] Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung, zu Berlin, vol. 8, 1907, p. 149.

[b] Idem, p. 162.

Kranepuhl's results are summarized in Table 5, in which positive tests mean that *B. coli* was found in 1 liter.

TABLE 5.—*Disinfection of crude Berlin sewage with chloride of lime.*

[Kranepuhl.]

Available chlorine (in parts per million.)	Time of exposure.	B. coli in liter samples.		
		Number of samples tested.	Number of positive tests.	Per cent of positive tests.
	Hours.			
50	2	20	11	55
50	4	9	2	22
60	2	17	6	35
60	4	6	3	50
150	2	19	4	21
150	4	10	1	10
300	2	16	1	6
300	4	7	0	0

Kurpjuweit[a] studied the penetration of solid particles by the disinfectant. He made test cubes of gelatine having a volume of about 10 cubic centimeters, which he immersed in solutions of chloride of lime for definite times, then removed and melted in warm water, after which he determined the available chlorine. He found the amount of available chlorine to be a regular function of the time of exposure and of the concentration of the solution. The most striking fact noted was the small quantity of chlorine actually absorbed. For instance, a cube that had been immersed for ninety hours gave a mean concentration of chlorine within its own volume equal to but 1 per cent of the concentration of the solution. There was also shown to be a chemical combination between the chlorine and the gelatine. In order to determine whether such chlorine was active in disinfection before it became combined, similar gelatine cubes, inoculated with *B. coli* before setting, were immersed for two hours in solutions containing from 60 to 3,000 parts per million of available chlorine. The results in Table 6 were obtained.

---

[a] Loc. cit.

TABLE 6.—*Destruction by chloride of lime of B. coli embedded in gelatine.*

[Kurpjuweit.]

Concentration of solution (average available chlorine in parts per million).	Number of B. coli remaining in 10 cubic centimeters after 2 hours.
0 (control)	91,500
60	55,400
150	43,500
200	48,100
300	6,600

The value of these results in practical work is problematic for several reasons. The cubes employed are much larger than the particles that should be in any sewage to be disinfected, and the character of the material is still more significant, because cubes of solid gelatine do not represent in any way the porous, semisoluble masses that occur in sewage. The question of penetration is an important one, and there can be no doubt that the practical efficiency of disinfection processes is limited by the ability of the disinfectant to penetrate small, solid particles that may be in the sewage. This point has been illustrated in a practical manner by Kurpjuweit's experiments. Four samples of crude sewage were screened through sieves having openings 2, 5, 7, and 10 millimeters in diameter, respectively. Four portions of each of the filtrates thus obtained were then treated with chloride of lime, so proportioned that the available chlorine was 150, 300, 600, and 3,000 parts per million, respectively. In the sewage that was screened through a 2-millimeter mesh, 150 parts per million of available chlorine destroyed all the *B. coli* in four separate liter samples, while the same concentration of chlorine destroyed the *B. coli* in only 5 out of 8 liter samples screened through the 10-millimeter mesh. Indeed, 3,000 parts of available chlorine were required to remove completely the *B. coli* in the samples screened through the 10-millimeter mesh.

It should be noted that the investigators at Hamburg and at Berlin dealt wholly with crude sewage. Even when purification plants are in operation the disinfection is invariably applied first. No good reason for this procedure is obvious, unless it is that preliminary sedimentation tanks are available and supplementary tanks are not. In Germany the method of operation is possibly justified by the fact that the processes are being studied in order that they may be adopted for temporary use during epidemics, and it is not proposed to practice disinfection regularly. The expense of treating crude sewage, however, is at least twice that of treating a well-purified filter effluent. The very high standards that have been established for this work are also of interest. It is proposed so to treat a sewage containing over 100,000 *B. coli* per cubic centimeter that the number of that kind of bacillus will be reduced to less than one in a liter. The result can hardly be expressed in per cent purification, and it is proper to inquire why such severe standards are employed. If the number of colon bacilli were reduced even to one per cubic centimeter, it would mean a reduction of 99.999 per cent. It may safely be inferred that the number of typhoid and cholera germs would be reduced in about the same ratio, and furthermore that the number of typhoid and cholera cases due to the discharge of this sewage would be similarly decreased. In other words, if such disinfection were generally adopted, 99,999 cases of disease out of every 100,000, which are due, directly or indirectly, to sewage pollution, would be eliminated. Such reduction would seem to be very satisfactory, and yet it is proposed to improve this a thousand fold by insisting on an elimination of the colon bacilli from 1-liter samples, thus making the cost so great that it practically prohibits the use of the process, except for short periods during serious epidemics. It is well worth considering whether a continuous removal of 99 per cent of the disease germs is not a better safeguard of the public health than an occasional complete removal during epidemics.

Experiments at Bengal, India.—The government of Bengal,[a] in 1904, appointed a commission to report on the pollution of Hooghly River by the effluents of septic tanks. Though the commission decided that the physical and chemical pollution of the river by the effluents was improbable, as sufficient dilution took place at all seasons to prevent any nuisance, bacterial purification of the effluents was deemed advisable. Experimental sand filters and copper sulphate disinfection satisfactorily removed the germs, but substitution of chloride of lime for the copper salt accomplished the same result at much less expense.

A septic tank installed near Calcutta was connected with a public latrine serving about 2,000 persons. From 400 gallons to 2,500 gallons of septic-tank effluent were daily treated with various amounts of chloride of lime, the available chlorine in which ranged from 20 to 60 parts per million. The numbers of bacteria initially present were not determined, but the final numbers are sufficiently low to indicate a satisfactory treatment. Furthermore, it was shown that increasing the concentration of the chlorine beyond a certain limit has very little effect on the residual bacteria. The results of this work are summarized in Table 7.

---

[a] Indian government resolution on the working of septic tanks. Calcutta, January 6, 1906.

TABLE 7.—*Disinfection of septic sewage by chloride of lime at Bengal, India.*

Available chlorine (in parts per million).	Number of tests.	Number of samples.	Bacteria remaining (average number per cubic centimeter).
20	9	31	33
30	7	24	10
40	8	28	48
60	7	25	52

Experiments in Ohio.—In 1907 the Ohio State Board of Health studied the disinfection of sewage effluents in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The results, reported by Kellerman, Pratt, and Kimberly,[a] related in part to the use of chloride of lime. The average results of four series of tests made with this disinfectant are summarized in Table 8.

TABLE 8.—*Disinfection of effluents with chloride of lime at Lancaster and at Marion, Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Available chlorine (in parts per million).	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	4.0	130,000	140	14,000	49	840	0
B	2.8	60,000	1,600	12,000	120	3,000	0
C	4.1	225,000	1,600	120,000	390	16,000	1
D	6.0	2,000,000	700,000	900,000	230,000	70,000	24,000

Each series represents a three-day test, during which 18 samples were examined in duplicate. Series A was made on the effluent of a sand filter at the Boys' Industrial School, Lancaster, and Series B, C, and D on the sand-filter effluent, contact-filter effluent, and septic-tank effluent, respectively, at Marion, Ohio. A subsequent study of the possibilities of treating the septic tank effluent at Marion led the authors to conclude that satisfactory disinfection could be accomplished by the use of sufficient bleaching powder to give 25 parts per million of available chlorine.

ELECTROLYTIC CHLORINE PROCESSES.

Electrolytic manufacture of chlorine.—When an electric current under a tension of not less than 2.5 volts is passed through a solution of common salt or of calcium or magnesium chloride, chlorine gas appears at one electrode and sodium hydroxide or the corresponding alkali at the other. In the electrolytic manufacture of chlorine the products of the dissociation are kept apart and are removed from the cell as quickly as possible, for if they are allowed to come together again they immediately unite and form a hypochlorite. This method of manufacturing hypochlorites has been employed in many of the so-called "electrolytic disinfection processes."

---

[a] Kellerman, K. F., Pratt, R. W., and Kimberly, A. E., The disinfection of sewage effluents for the protection of public water supplies: Bull. 115, Bur. Plant Industry, U. S. Dept. Agr., 1907.

The Webster process.—One of the earliest electrolytic treatments was devised by Webster over twenty years ago, when, in 1889, he installed an experimental electrolytic plant at Crossness, England, to treat London sewage.[a] In his process crude sewage flowed between iron electrodes placed in long troughs, and an electric current was passed from one electrode to the other at a tension of only two volts and a current density of 0.9 ampere per square foot of electrode. It was estimated that the treatment of 1,000,000 gallons of crude sewage required the consumption of 240 pounds of iron and 450 kilowatt-hours of electricity. Sedimentation followed the electrical treatment, and a large amount of material was removed. In fact the process was virtually one of chemical precipitation, the iron dissolved from the electrode being first converted into hypochlorite, or other salt, and then being decomposed by the alkali present and precipitated. The solution of iron at the positive pole allowed the electrolytic reaction to proceed at a lower voltage than that required to liberate free chlorine. The results shown in Table 9 are the averages of 20 analyses, and they indicate the degree of purification obtained by the Webster process.

TABLE 9. *Analyses of London sewage before and after treatment by the Webster process.*

	Parts per million.	
	Initial.	Final.
Suspended solids	333.5	15.6
Nitrogen as free ammonia	43.4	32.2
Albuminoid ammonia	5.0	2.0
Oxygen consumed	12.4	5.2

Though the process was originally conducted as a chemical precipitation, credit is due Webster for first pointing out the disinfecting value of the hypochlorites that are formed. T. M. Drown,[b] commenting on the process, observed that the American Public Health Association recognized the value of hypochlorites as early as 1888, and that their electrolytic manufacture was nothing new. Nevertheless its application to sewage was new and gave promise of success.

---

[a] The Engineer, London, vol. 67, 1889, p. 261; also Eng. News, vol. 21, 1889, p. 338; vol. 22, 1889, p. [illegible]

[b] Jour. New England Waterworks Assoc., vol. 8, 1894, p. 135; also Eng. News, vol. 31, 1894, p. [illegible]

In a later paper before the British Medical Association[a] Webster called attention to the possibilities of electrolyzing sea water and thus laid the foundation for the many later processes that are based on that principle. A plant was later installed at Bradford, England, and in 1890 Doctor McLintock stated that 70 per cent of the putrescible organic matter of the sewage had been removed.[b]

Fermi,[c] after having investigated the process at the hygienic institute at Munich, concluded that the process is one of chemical precipitation and that it is more expensive than the lime process, and similar conclusions were reached by König and Remele.[d]

The Woolf process—Electrozone.—Woolf's process differed from Webster's in that strong brine was electrolyzed, and the resultant chlorine and caustic soda were allowed to recombine to form sodium hypochlorite. The hypochlorite solution was then added to the sewage or water to be treated. In the spring of 1893 a plant of this kind was installed under the direction of the health department of New York City for treating the sewage of about 31 dwellings at Brewster, N. Y.,[e] a village situated on a small stream, the waters of which discharge into Croton Lake. The experiment was considered so successful that the health department installed a similar plant at the same place to discharge hypochlorite solution into Tonnetta Creek.[f] Sixteen hundred pounds of salt per million gallons of sewage were used, and the plant required an electric current of 700 amperes at 5 volts tension. This seems to have been the first plant established for the specific purpose of destroying bacteria; before that time the removal of organic matter had been the aim. An electrozone plant installed at Maidenhead, England, in 1897, was examined by Rideal, Robinson, and Kanthack in 1898. The bactericidal action was marked and the effluent was found to contain but few bacteria; this plant was not, however, continued[g] in operation. At Havana, Cuba, the Woolf process was employed for preparing a disinfectant solution to be used for treating the streets and the harbor.

The Hermite process.—The Hermite system differs from the Woolf system only in minor details. In reports on the process great stress is laid on the presence of magnesium hypochlorite in the electrolyzed solution, and there is much evidence that magnesium hypochlorite, owing probably to its lesser stability, is a more active agent than other hypochlorites. In later years this same fact has been observed, and it has been the basis of fanciful claims for patented processes, whose owners have invoked hypothetical oxides of chlorine to explain the results. A commission appointed by the London Lancet to investigate the Hermite process found that the solution obtained was similar to ordinary hypochlorite[a] in its chemical properties. A plant installed at Worthing, England, was investigated in 1894 by Kelly,[b] who reported that the hypochlorite solution contained from 0.22 to 0.75 gram per liter of available chlorine. The claim made for this solution—that mixed with equal parts of sewage it would instantly kill all germs—was not substantiated. A plant employing the Hermite process, established at Havre, France, in 1893, was investigated by a commission appointed by the imperial board of health of Germany and by one sent from Paris by the council of hygiene, and both bodies reported adversely. Other Hermite plants were installed at various places, but were finally abandoned. At Poplar, England, the Hermite solution is prepared on a large scale, and it is used for general disinfecting purposes as well as for street watering.

---

[a] Eng. News, vol. 22, 1889, p. 388.

[b] Brit. Med. Jour., vol. 2, 1890, p. 498.

[c] Arch. f. Hyg., vol. 13, 1891, p. 207.

[d] Arch. f. Hyg., vol. 28, 1897, p. 185.

[e] Eng. News, vol. 30, 1893, p. 41.

[f] Eng. Record, vol. 29, 1894, p. 110; Elec. Eng., vol. 18, 1894, p. 101.

[g] Rideal, S., Sewage and its purification, 3d ed., New York, 1906, p. 185.

The oxychloride process.—The oxychloride process differs from the Hermite and Woolf processes only in matters of detail in the electrolytic cell. Greater efficiency than the older processes in the production of hypochlorites is claimed for it. At Guilford, England, Rideal made a test of the effect of oxychloride treatment on raw and septic sewages and on effluents of primary, secondary, and tertiary contact beds. The summary of his results given in Table 10 shows what was accomplished. The results, especially in respect to the removal of *B. coli*, are all that can be desired.

TABLE 10.—*Summary of Rideal's experiments on the use of oxychloride at Guilford, England.*

Source of sample.	Available chlorine parts per million.	Time of contact.	Number of organisms per cubic centimeter.					
			Total.		B. coli.		B. enteritidis.	
			Initial.	Final.	Initial.	Final less than—	Initial.	Final less than—
Sewage	30	4.3 hours	23,000,000	50,000	1,000,000	1.0	1,000	10.0
	50	do	23,000,000	20	1,000,000	.2	1,000	.2
	70	do	23,000,000	10	1,000,000	.2	1,000	.2
Septic effluent	25–44	1 to 4 hours	2,500,000–4,500,000	20–600	100,000–1,000,000	1.0–.2	10–1,000	1.0–.2
Effluent from first contact bed.	20	40 minutes			100,000	.2		
	20	2 hours					20–100	.2
Effluent from second contact bed	10.6		1,000,000–2,000,000	40	1,000,000	.2	10–1,000	
Effluent from third contact bed.	2.5	1 hour			1,000–10,000	.2		
	2.5	4.5 hours					10–1	
	.5	0.5 hour			1,000–10,000	.2		
	.5	4.5 hours					10–1	

---

[a] Lancet, vol. 1, 1894, p. 1221.

[b] Public Health, vol. 6, 1894

Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group—aerobic spore-forming bacteria which are probably beneficial in the further oxidation of the organic matter. Absolute sterilization required very high concentration of chlorine.

COPPER AND ITS COMPOUNDS.

Moore and Kellerman, in 1904, suggested that copper sulphate be used in water sterilization.[a] Since that time a great deal of experimental work has been done, mainly in connection with water. The more important experiments, with sewage will be outlined.

Johnson and Copeland[b] at Columbus, Ohio, in 1904, in their work with trickling filter effluents, obtained the results given in Table 11.

TABLE 11.—*Disinfection of trickling filter effluents with copper sulphate at Columbus, Ohio.*

[Johnson and Copeland.]

	Copper sulphate in parts per million.	Reduction in bacteria (per cent).	
		In 3 hours.	In 24 hours.
First series, average of 3 sets	5	90.0	99.9
	10	98.0	99.95
	20	98.5	99.96
Second series, average of 3 sets	10	40.0	99.7
	20	60.0	99.9
	40	88.0	99.95

They found the action of copper sulphate to be most rapid during the first hour. They estimate the cost for chemicals alone at $5 per million gallons of effluent treated with 10 parts per million of copper sulphate, and $10 if treated with 20 parts per million—an expense which they consider prohibitive.

The use of copper sulphate as a disinfectant was more thoroughly investigated by Johnson at Columbus in 1905.[c] Experiments were made with crude sewage, and with effluents from trickling, contact, and sand filters. The effect of temperature, of organic matter, and of alkalinity on the efficiency of the process were determined and special studies were also made to determine the effect of the treatment on colon and typhoid organisms. The principal results with the various sewages treated are summarized in Table 12.

---

[a] U. S. Dept. Agr., Bureau of Plant Industry, Bull. 64, 1904.

[b] Jour. Infect. Diseases, Suppl. No. 1, 1905, p. 327; also Reports and papers, Am. Pub. Health Assoc. vol. 30, pt. 2, p. 327.

[c] Report on sewage purification at Columbus, Ohio, 1905, p. 471; also Jour. New England Waterworks Assoc., 1905, p. 474.

TABLE 12.—*Results of disinfection of sewage and effluents with copper sulphate at Columbus, Ohio; total number of bacteria remaining after contact periods of one hour and of three hours.*[a]

[Johnson.]

Copper sulphate (in parts per million.)	Series A.	Series B.		Series C.		Series D.	
	1 hour.	1 hour.	3 hours.	1 hour.	3 hours.	1 hour.	3 hours.
1,000	3,000	1,000	240	430	60	2,100	280
200	....	5,000	600	1,100	130	6,000	1,400
100	9,000	6,000	500	2,100	230	5,500	1,800
40	....	3,400	700	1,200	230	6,500	1,300
20	14,000	11,000	1,900	3,500	600	13,000	2,600
10	....	21,000	4,500	7,500	1,200	20,000	5,000

	Bacteria per cc.
[a] Series A. Crude sewage; initial number	1,200,000
B. Effluent of sprinkling filter	1,000,000
C. Effluent of contact filter	400,000
D. Effluent of sand filter	280,000

Each series is the average of from three to five sets of tests.

Longer periods of contact up to twenty-four hours gave results of no additional significance, except that when the lower concentrations of copper were used the number of bacteria showed a decided increase after about the third hour, an indication that the copper was removed from solution, probably by combination either with the organic matter or with carbonic acid. Subsequent increase in number of bacteria is a phenomenon of frequent occurrence in disinfection work. It is in fact neither possible nor desirable to prevent perpetually the feeding of bacteria on the organic matter of the disinfected effluents. The significant fact in Johnson's tests is that the bacteria originally present were practically eliminated, and it may safely be assumed that under conditions existing in a stream there would be no multiplication of the typhoid or other pathogenic bacteria.

Two important facts were brought out in this study. The disinfection obtained with 100 parts per million of copper sulphate is, for practical purposes, but little better than that obtained with 10 parts, and results obtained in a one-hour contact are practically as good as those obtained in a three-hour contact. Johnson's work was done at summer temperature, and in order to determine the effect of temperature on the germicidal action parallel experiments were conducted at 5° and at 20° C. It was found in general that a result which could be obtained at the higher temperature in thirty minutes would be attained at the lower temperature in about three hours. This is a point that has usually been overlooked, and it is of special significance in practical operation, as effluents in the northern latitudes would have a temperature of about 5° C. during much of the year. It is interesting to note that temperature has little effect on the germicidal efficiency of hypochlorites.

The combined effect of organic matter and alkalinity was determined by treating the undiluted effluent and the same effluent after being diluted 1 to 1 and 1 to 2 with tap water. The effect was decidedly noticeable in the weaker concentrations of copper sulphate, and much less so where the concentrations of copper were excessive. The results with 10 parts of copper sulphate per million are summarized in Table 13.

TABLE 13.—*Effect of organic matter and of alkalinity on the germicidal properties of copper sulphate: per cent removal of bacteria at end of one hour's contact with 10 parts per million of copper sulphate.*

[Johnson.]

Source of sample.	Dilution.		
	0	1:1	1:2
Crude sewage	96.1	97.5	98.5
Trickling filter effluent	97.3	99.0	99.1
Sand filter effluent	70	86	91

The efficiency of copper sulphate as a disinfectant was investigated in 1906 at the Sanitary Research Laboratory of the Massachusetts Institute of Technology by treating the effluent from an 8-foot trickling filter. Table 14 gives the average results divided into two periods to show the effect of temperature of the effluent. At the conclusion of the tests a composite sample of the sediment drawn from the sedimentation tank during the experiment was analyzed. The copper contained in the sediment accounted very closely for the total amount of copper added, a fact that makes it apparent that little copper left the tank in soluble form.

TABLE 14.—*Disinfection of trickling filter effluent with copper sulphate at Boston, Mass.; average results.*

Period.	Copper sulphate (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			Number of B. coli[a] per cubic centimeter.		
			Initial.	Final.	Per cent removed.	Initial.	Final.	Per cent removed.
1906.		°F.						
October 13-31	4	56	230,000	14,000	94.0	44,000	640	98.5
November 3-19	4	46	250,000	51,000	80.0	48,000	770	98.4
November 21-December 10	8	43	240,000	5,000	97.9	32,000	390	98.8

[a] Jackson's bile media used.

The work of Kellerman, Pratt, and Kimberly in Ohio during the winter of 1906-7 consisted mainly of experiments with copper sulphate as a disinfectant. Their investigations, probably the most comprehensive ever made with copper sulphate, were conducted under actual working conditions and with several kinds of effluent. The chemical composition of the water, particularly in regard to its hardening constituents, was found to exert an important influence on the results. Their original paper[a] on the subject contains complete chemical analyses of the effluents treated. Table 15, containing a brief summary of average results calculated from the original tables, shows in a general way what was accomplished. The authors concluded that copper sulphate is not so efficient as chlorine compounds, is more seriously affected by carbonates, and is much more expensive.

TABLE 15.—*Disinfection of effluents with copper sulphate in Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Copper sulphate (in parts per million)	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	5	6,000,000	1,200,000	140,000	120,000	6,000	600
	6.7	250,000	70,000	19,000	10,000	6,000	900
	10	60,000	16,000	47,000	10,000	2,600	1,000
	13	65,000	23,000	37,000	5,500	4,600	600
	20	120,000	20,000	8,000	11,000	1,600	110
	29	60,000	3,900	24,000	6,000	1,200	10
	40	160,000	8,500	75,000	4,700	5,500	110
	67	200,000	34,000	81,000	14,000	7,000	700
B	7.3	110,000	23,000	12,000	1,800	600	48
	14	75,000	9,500	16,000	600	75	0
	22	55,000	7,000	5,500	200	75	0
C	6.5	390,000	110,000	170,000	41,000	8,000	3,000
	15	230,000	65,000	42,000	16,000	5,000	2,200
	40	29,000	6,000	30,000	8,500	5,500	750
	116	84,000	7,000	28,000	2,000	5,000	560

A. Effluent of contact filter at Westerville, Ohio.
B. Effluent of sand filter at Lancaster, Ohio.
C. Effluent of sand filter at Marion, Ohio.

MISCELLANEOUS METHODS.

PERMANGANATES.

Potassium permanganate and sodium permanganate have been used for the oxidation of organic matter in streams. At London when the Thames becomes extremely foul during low-water periods, sodium permanganate is added to its waters in order to destroy odors and putrescible material, but the treatment undoubtedly results in partly sterilizing the water. It is claimed that the germicidal action is not sufficiently great to interfere with the normal oxidizing changes in the stream. The use of permanganates has been proposed for rendering effluents of chemical precipitation plants nonputrescible.

"AMINES" PROCESS.

The so-called "amines" process was developed by H. Wollheim in England. It is claimed that trimethylamine treated with lime or other alkali produces a very poisonous substance. Herring brine is used to supply the amine. A large excess of lime is added and the mixture is used to precipitate crude sewage. Klein made a test of the process at West Horn in 1889, and found that a clear, nonputrescent, sterile effluent could be obtained. Similar results were obtained at Wimbledon,[a] where 768,000 bacteria per cubic centimeter in the sewage were completely removed. The sludge is also nonputrescible. The process does not seem to have been further developed.

---

[a] Kellerman, K. T., Pratt, R. W., and Kimberly, A. E.: The disinfection of sewage effluents for the protection of public water supplies, Bull. 115, Bur. Plant Industry, U. S. Dept. Agr. 1907.

SODIUM BENZOATE AND OTHER ORGANIC COMPOUNDS.

Sodium benzoate is supposed to possess powerful germicidal properties, and its use as a disinfectant for sewage was suggested to the writer. It would apparently have the distinct advantage over such other disinfectants as chlorine and copper salts of not combining with organic matter, thus rendering all the disinfectant added available for a long time. Sodium benzoate was applied regularly to a trickling filter effluent at Boston during March and April, 1907. An addition of commercial benzoate at the rate of 0.8 part per million for twenty-six days gave an average reduction of total bacteria from 140,000 to 54,000 per cubic centimeter, or a 62 per cent removal. Doubling the amount of benzoate increased the efficiency somewhat, the average reduction then being from 370,000 to 84,000 per cubic centimeter, or 78 per cent. The cost of benzoate for the treatment is $1 per million gallons for 0.8 part and $2 for twice that quantity. Obviously this substance is not an efficient disinfectant in sewage work.

Other organic substances, such as the phenols and the coal-tar products, were suggested, but in general their high cost eliminates them from consideration. The possibility of after effects must also be considered. There is a certain advantage in the use of a substance which is itself used up in the reaction or which is converted into harmless compounds. On the other hand, the organic disinfectants are extremely powerful and there is always a chance of the discovery of some new compound with the requisite germicidal properties and the low cost that will make it the ideal sewage disinfectant.

SUMMARY OF DISINFECTION METHODS.

Two of the methods of disinfection that have been mentioned appear not to have been sufficiently investigated, namely, disinfection by heat and by organic compounds. The heat method holds a reasonable possibility that sufficient ammonia may be recovered to pay for the necessary heating, but actual trial is essential for convincing proof. A systematic study of organic compounds as disinfectants has yet to be made.

---

[a] Interim *Rept. Royal Sewage* Commission, 1901, p. 394.

Of the disinfectants that have been sufficiently investigated chlorine compounds and copper salts alone appear to be applicable to the sewage problem. Moreover, a detailed study of results on a cost basis leaves no doubt that the efficiency of chlorine is much greater than that of copper. Even if the prices of these two materials were more nearly equal, many facts favor the use of chlorine. Both reagents unite with organic matter, but chlorine unites by oxidizing the organic matter, thus rendering it less putrescible, while copper precipitates it. The compounds formed by the copper tend to protect the solid particles from further action, and the diffusion of copper ions through such a precipitated copper envelope must necessarily be slow. As no such action occurs with chlorine compounds, the penetration of the chlorine into solid particles must be much more complete. Chlorine in the form of bleaching powder is to some extent a by-product, is very cheap, and will probably become cheaper as the methods of production are improved; on the other hand copper is a staple, the price of which is likely to increase. Sewage may be found of such chemical composition that treatment with copper will be more effective than that with chlorine, but in general chlorine compounds are to-day by far the most economical and the most efficient disinfectants available in sewage work.

EXPERIMENTAL INVESTIGATIONS.

HISTORY.

In connection with general investigations in sewage disposal, which have been conducted since 1903 at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology, the subject of the chemical disinfection of sewage and sewage effluents has been extensively studied during the past two years. In the spring of 1906 a cooperative arrangement between the United States Geological Survey and the institute made it possible materially to enlarge the scope of the work.

With a view also of gaining increased knowledge of the practical workings of the processes that had been developed at Boston, an arrangement was made with the state sewerage commission of New Jersey, through Boyd McLean, secretary, under which experiments were begun at Red Bank, N. J. The state sewerage commission later continued that work for its own information, retaining the writer in charge, and through the courtesy of the commission the results of the entire work are here presented. During the summer of 1907 the experiments were placed under the immediate charge of F. E. Daniels, to whose faithful efforts their successful completion is in large part due. Mr. Daniels was assisted at Red Bank by H. S. Crawford, and also did much of the work at Boston during 1908.

In December, 1907, the scope of the investigation was still further broadened by a cooperative agreement between the United States Geological Survey and the sewerage commission of Baltimore, of which Brig. Gen. Peter Leary, U. S. Army, retired, is chairman, and Calvin W. Hendrick is chief engineer. Experiments on a somewhat enlarged scale were immediately undertaken at the Walbrook testing station of the Baltimore sewerage commission, and they were continued up to July, 1908, at which date the agreement with the Geological Survey lapsed. The work at Baltimore was under the immediate charge of Ezra B. Whitman, division engineer of the disposal division, to whom the writer is under the greatest obligation for its successful outcome. Intimately associated with that work also and responsible in large measure for the results have been Charles A. Emerson, jr., assistant division engineer, Henry C. McRae, chemist, and Edward G. Birge, bacteriologist. Dr. R. P. Cowles, of Johns Hopkins University, and William T. Carpenter, Leyland Whipple, and Marvin H. Lillis, have also been associated with this work from time to time in connection with special lines of investigation.

Through the courtesy of A. G. Paine, jr., president, and J. R. Crocker, superintendent, of the McDonald Electrolytic Cell Company, of New York, an electrolytic chlorine cell having a capacity of 22 pounds a day of chlorine gas was placed at the disposal of the writer, and it proved to be of great assistance in the work, as a large supply of gaseous chlorine was thus made available for special experiments. The machine was used directly in disinfection and also in the preparation of a series of chlorine compounds that were studied.

BACTERIOLOGICAL METHODS AND EXPRESSION OF RESULTS.

The bacteriological methods employed in the different parts of this work have been kept as nearly uniform as possible in order that the results may be strictly comparable. In general, the methods have been those recommended by the committee on standard methods of water analysis of the American Public Health Association, laboratory section. Since the publication of those methods,[a] a new presumptive test for the colon bacillus has been described by Jackson[b] and it has been used throughout this work. The medium employed in this test consists of ox bile to which lactose has been added. Its accuracy in sewage work has never been carefully studied, but recent studies by Prescott and Winslow[c] have confirmed the earlier statement of Jackson that in water work this presumptive test gives results which are similar to those obtained in complete *B. coli*

determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli*, and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli*. An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

---

[a] Jour. Infect. Dis. Suppl. 1, Chicago, 1905. Repts. and Papers American Pub. Health Assoc., vol. 30, pt. 2, 1905.

[b] Biological studies by the pupils of William Thompson Sedgwick, p. 292, Boston, 1906.

[c] Elements of water bacteriology, 2d ed., New York, 1908, p. 148.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant *as the average figure* itself. Accordingly, the routine work is reported

in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown[a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages ust be properly interpreted, but monthly averages are probably ry near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

ince the beginning of the work at Boston in February, 1906, ous phases of the disinfection problem have been under investi- on. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the compar

determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli*, and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli*. An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

---

[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of d
Jour. Pub. Hyg., vol. 18, 1908, p. 141.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant as the average figure itself. Accordingly, the routine work is reported

in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown[a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the comparative effect

determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli*, and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli*. An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

---

[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of dilution tests. Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant *as the average* figure itself. Accordingly, the routine work is reported

in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown [a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the compar[illegible]ive effect of hypochlorites on the typhoid and the colon bacilli; (*e*) routine disinfection of 5,000 gallons a day of trickling-filter effluent with chloride of lime; (*f*) disinfection of crude sewage with chloride of lime in 700-gallon tests. The studies on copper sulphate and sodium benzoate have already been discussed (pp. 29–32). The remaining divisions of the work are reviewed in the succeeding pages.

---

[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of [illegible]rtation tests: Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

PRELIMINARY EXPERIMENTS WITH CHLORIDE OF LIME.

The results of some preliminary experiments in the spring of 1906 have already been published,[a] but as they have important bearing on the present work, a brief review of them is here presented. The experiments were made with chloride of lime and the effluent of a trickling filter in which Boston sewage was being treated. They consisted of 23 bottle tests in which the available chlorine that was added varied from 0.25 to 100 parts per million, and the time of contact from thirty minutes to twenty-four hours. They were undertaken with the object of establishing practical working limits for available chlorine and contact period for future experiments, and particularly to determine whether the English and Continental practice of adding large, almost prohibitive, amounts of chlorine is justified by the results.

This preliminary study indicated that an effluent similar to the one used can be deprived of 95 per cent to 98 per cent of its total bacteria in two hours by the application of chloride of lime in concentrations having 2 to 5 parts per million of available chlorine. The impracticability of attempting to get much better results was well shown, for complete sterilization was never accomplished, though concentrations of chlorine up to 100 parts per million and storage periods of twenty-four hours were employed. It was found unnecessary, in brief, to use more than 5 parts of chlorine or to treat for over two hours.

It is a well-known fact that, in all processes involving the destruction of bacteria, it is comparatively easy to kill the first 95 per cent of the germs and very difficult to destroy the remaining 5 per cent. This phenomenon of the "resistant minority," as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals, or other means. It is therefore more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To state a concrete example, it might happen that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money, 97 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first reduction might represent a feasible plan, and the last a prohibitively expensive one. It is plainly more desirable at the outset to determine the relations between the various factors, such as concentration of disinfectant, time of contact, cost, and efficiency, and to establish certain working limits with reference to final costs, than to attempt the ultimate destruction of all germs regardless of the practical limits that necessarily exist. The preliminary experiments were undertaken with the idea of fixing these practical working limits. For the first time in the history of the subject the disinfection of sewage filter effluents and even of crude sewage itself was shown to be practicable and feasible, yielding results commensurate with the cost when compared with the results and costs of other purification processes.

---

[a] *Phelps, E. B.,* and Carpenter, Wm. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, 1906, pp. 382–403.

DISINFECTION OF TRICKLING-FILTER EFFLUENT.

The most important work at Boston consisted in the routine disinfection of the combined effluents of two trickling filters. Each filter is 8 feet deep and has a surface area of 50 square feet. One is composed of crushed stone from 1 inch to 1½ inches in mean diameter; the other of stone from 1½ to 2 inches in diameter. The combined effluents, amounting to 5,000 gallons in twenty-four hours, were brought from the underdrains of the outdoor trickling filters to the filter house through a short length of iron pipe. Within the filter house the liquid was conducted by an open trough to the central channel of a sedimentation tank built on the Dortmund plan. It then passed downward nearly to the bottom of this conical tank, entered the main body of the tank, and, rising with constantly decreasing velocity, finally overflowed at the surface. The tank was designed to give a two-hour storage period. The disinfectant solution was made up in a 50-gallon barrel to a strength about one hundred times that required in the final mixture. A small orifice-box working under constant head was connected with the barrel and was designed to deliver exactly 2 gallons an hour. As the flow through the sedimentation tank was a little over 200 gallons per ur, this arrangement gave a final mixture of the desired propor- us. These rates and volumes were kept constant throughout, change in the amount of disinfectant added being brought about hanging the strength of the solution. Readings of a float gauge the barrel and daily measurements of the flow of the trickling- effluent into the tank served as checks on the accuracy of the ns, and together with daily analyses of the strong disin- solution, gave data from which the actual amount of dis- ectant added during any required period of time could be computed. Observations of the rate of flow of the disinfectant solution into the tank were made at hourly intervals for a period of hours preceding the taking of samples, and the actual conce of the *disinfectant corresponding* to the sample in ques determinations. It may fairly be assumed, therefore, that the coli results reported in the present paper represent a group of b teria, including practically all the *B. coli* actually present, togeth with certain other bacteria which probably are not more than per cent of the whole number reported. The study of such a gro gives valuable information concerning the probable elimination typhoid and other pathogenic bacteria, while the additional inf mation to be obtained from a complete determination of the *B.* actually present is not deemed sufficient to warrant the additio labor involved. At Boston and at Baltimore counts of the bacte on gelatin at 20° C. and on litmus lactose agar at 37° C. counts of the acid-forming bacteria at 37° C. were recorded. Th latter group includes the *B. coli*, and some bacteriologists belie that the number of acid-forming bacteria is a more accurat indication of the numbers of colon bacilli than the presumptiv tests. It is indisputable, however, that the group of aci forming bacteria is large and that in sewage work at least bears only a general relationship to *B. coli*. An additional grou the bacteria that liquefy gelatin, is also included in the Boston result though the additional information afforded by including this grou is slight. Inasmuch as adequate facilities for complete bacteriologic work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In *other words, the* from the average are fully as significant *as the* cordingly, the routine work is r

in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown [a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the comparative effect

determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli*, and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli*. An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

---

[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of dilution tests. Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant as the average figure itself. Accordingly, the routine work is reported

in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown [a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the comparative effect

of hypochlorites on the typhoid and the colon bacilli; (*e*) routine disinfection of 5,000 gallons a day of trickling-filter effluent with chloride of lime; (*f*) disinfection of crude sewage with chloride of lime in 700-gallon tests. The studies on copper sulphate and sodium benzoate have already been discussed (pp. 29–32). The remaining divisions of the work are reviewed in the succeeding pages.

---

[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of dilution tests. Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

PRELIMINARY EXPERIMENTS WITH CHLORIDE OF LIME.

The results of some preliminary experiments in the spring of 1906 have already been published,[a] but as they have important bearing on the present work, a brief review of them is here presented. The experiments were made with chloride of lime and the effluent of a trickling filter in which Boston sewage was being treated. They consisted of 23 bottle tests in which the available chlorine that was added varied from 0.25 to 100 parts per million, and the time of contact from thirty minutes to twenty-four hours. They were undertaken with the object of establishing practical working limits for available chlorine and contact period for future experiments, and particularly to determine whether the English and Continental practice of adding large, almost prohibitive, amounts of chlorine is justified by the results.

This preliminary study indicated that an effluent similar to the one used can be deprived of 95 per cent to 98 per cent of its total bacteria in two hours by the application of chloride of lime in concentrations having 2 to 5 parts per million of available chlorine. The impracticability of attempting to get much better results was well shown, for complete sterilization was never accomplished, though concentrations of chlorine up to 100 parts per million and storage periods of twenty-four hours were employed. It was found unnecessary, in brief, to use more than 5 parts of chlorine or to treat for over two hours.

It is a well-known fact that, in all processes involving the destruction of bacteria, it is comparatively easy to kill the first 95 per cent of the germs and very difficult to destroy the remaining 5 per cent. This phenomenon of the "resistant minority," as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals, or other means. It is therefore more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To state a concrete example, it might happen that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money, 97 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first reduction might represent a feasible plan, and the last a pro-

---

[a] Phelps, E. B., and Carpenter Wm. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19. 1906, pp. 382–403.

[illegible] to determine the [illegible] of disinfectant [illegible] to establish certain working [illegible] that it attempt the ultimate [illegible] limits than [illegible] were maintained [illegible] of sewage [illegible] effluents [illegible] with [illegible] purposes.

[illegible]

The most [illegible] disinfection of the [illegible] filter is 8 feet deep and [illegible] composed of crushed [illegible] eter; the other of stone [illegible] bined effluents, amounting to [illegible] were brought from the [illegible] to the filter house through a short length of iron pipe. Within the filter house the liquid was conducted by an open flume to the central channel of a sedimentation tank built on the Dortmund plan. It then passed downward nearly to the bottom of the conical tank, entered the main body of the tank, and, rising with constantly decreasing velocity, finally overflowed at the surface. The tank was designed to give a two hour storage period. The disinfectant solution was made up in a 50 gallon barrel to a strength about one hundred times that required in the final mixture. A small orifice box working under constant head was connected with the barrel and was designed to deliver exactly [illegible] gallons an hour. As the flow through the sedimentation tank was a little over [illegible] gallons per hour, this arrangement gave a final mixture of [illegible] proportions. These rates and volumes [illegible] any change in the amount of [illegible] by changing the strength of [illegible] set in the barrel and [illegible] filter effluent into the [illegible] dilutions, and together [illegible] fecting solution, [illegible] infectant added [illegible] puted. Observations [illegible] into the tank were [illegible] hours preceding [illegible]

Disinfectant [illegible]

calculated from these observations. The disinfectant solution flowed into the open trough previously mentioned, where it mingled with the effluent. Further opportunity for mixing occurred during the passage down the central channel of the sedimentation tank. Samples for bacterial examination were collected with the usual precautions, before the effluent had reached the wooden trough into which the disinfectant solution was run and also at the final outlet of the sedimentation tank after the combined effluent and disinfectant had been in contact for a period somewhat less than two hours. These samples are described as initial and final, respectively.

The chemical composition of an effluent has an important influence on the germicidal value of most disinfectants, particularly chloride of lime. The chlorine applied is eventually completely consumed by chemical reaction with the organic matter of the effluent, and the germicidal action takes place in the interval of time between the addition of the chlorine and its final exhaustion by chemical reaction. The amount of organic matter present, therefore, practically determines the amount of chlorine that it is necessary to use. For this reason the chemical analyses of the combined effluent are recorded by monthly averages in Table 16. The monthly averages of the analyses of the disinfected and settled effluent are also included to show the chemical character of the effluent after treatment.

TABLE 16.—*Chemical analyses of trickling-filter effluent at Boston before and after disinfection with chloride of lime and sedimentation; monthly averages.*

[Parts per million.]

INITIAL.

Month.	Turbidity.	Suspended solids.		Nitrogen as—					Oxygen consumed.[a]		Dissolved oxygen.
		Total.	Loss on ignition.	Organic.		Free ammonia.	Nitrites.	Nitrates.	Total.	Dissolved.	
				Total.	Dissolved.						
1907.											
November	135	118	78	3.5	1.5	15.0	0.2	2.0	40	32	8.2
December	155	......	......	5.5	3.0	15.5	0.1	1.0	38	33	7.8
1908.											
January	140	92	69	5.0	3.0	15.0	0.3	3.5	45	38	10.0
February	145	177	156	6.0	2.5	14.5	0.1	3.0	44	32	12.5
March	130	180	122	7.5	3.5	15.5	0.2	4.0	48	35	7.8
April	195	313	192	10.5	5.5	14.5	0.4	5.5	64	46	9.4
May	275	436	247	14.0	4.5	14.5	0.9	6.0	70	35	7.4
June	155	174	96	11.5	6.0	7.5	0.8	6.0	49	35	7.1
Average	165	213	137	8.0	4.0	14.0	0.4	4.0	50	36	8.8

FINAL.

Month.	Turbidity.	Suspended solids.		Nitrogen as—					Oxygen consumed.[a]		Dissolved oxygen.
		Total.	Loss on ignition.	Organic.		Free ammonia.	Nitrites.	Nitrates.	Total.	Dissolved.	
				Total.	Dissolved.						
1907.											
November	105	71	53	3.0	1.5	14.5	0.1	2.0	28	27	......
December	145	......	......	4.0	1.5	14.0	0.1	2.0	39	38	......
1908.											
January	115	124	103	3.0	3.0	13.0	0.6	5.0	49	41	......
February	110	259	239	4.5	2.5	13.5	0.3	4.5	42	38	......
March	125	125	82	9.5	3.5	15.0	0.3	3.5	46	42	......
April	105	147	125	5.5	3.5	14.5	0.4	5.0	44	40	......
May	135	92	69	5.0	3.0	15.0	1.0	5.0	44	33	......
......	95	51	43	7.0	4.0	7.5	0.8	6.0	38	33	......
Average	115	124	102	5.0	3.0	13.5	0.5	4.0	41	37	......

[a] Thirty-minute boiling method.

This disinfection experiment was started November 11, 1907, and was continued practically without interruption till June 27, 1908, a period of thirty-three weeks. The value of such continuous experiment is obvious. A certain length of time is always required for for the establishment of uniform working conditions, not only in the personal element but in the tanks themselves. Furthermore, short special experiments receive an unusual and perhaps unfair amount of care and attention, which is not bestowed on work that has become part of the routine, and the natural defects of the processes under practical working conditions are, therefore, not always discovered. The most important value of long-continued tests, however, lies in their being carried out under various seasonal conditions. Fluctuating conditions of temperature and rainfall fundamentally affect the sewage and influence the work of the filter. It is consequently of prime importance to determine the efficiency of any purification process under an extreme range of seasonal conditions. It fortunately happened that the present experiments were continued through an unusually cold winter and through the hottest portions of an exceptionally hot, dry summer.

Table 17 contains the results of the experiments, given in weekly averages, which are the mean of four to six daily results. During the first five weeks the available chlorine added was about six parts per million, but during the remainder of the period this concentration was reduced to between two and four parts without materially affecting the results. The average results for the whole period are indicated in the last line of the table.

TABLE 17.—*Disinfection of trickling-filter effluent with chloride of lime at Boston; weekly averages.*

Week ending—	Temperature.	Available Cl (parts per million).	Number of bacteria per cubic centimeter at 20° C.				Number of bacteria per cubic centimeter at 37° C.				Number of B. coli per cubic centimeter.[a]	
			Total.		Liquefiers.		Total.		Acid formers.			
			Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1907.												
November 16	45	5.7	1,100,000	1,500	150,000	100	330,000	570	230,000	22	260,000	4
23	46	5.9	800,000	7,500	46,000	600	130,000	500	94,000	250	180,000	20
30	42	6.8	1,000,000	1,800	48,000	43	65,000	600	48,000	110	26,000	1
ecember 7	36	6.9	600,000	4,500	60,000	90	140,000	140	85,000	44	17,000	0
14	42	5.0	800,000	15,000	60,000	750	140,000	1,500	43,000	850	5,500	33
21	37	3.0	550,000	85,000	27,000	4,500	95,000	6,500	75,000	5,500	4,000	370
28	44	3.1	550,000	20,000	120,000	2,400	210,000	3,400	66,000	1,900	46,000	600
1908.												
nuary 4	40	2.8	950,000	7,000	70,000	500	90,000	500	70,000	370	65,000	25
11	35	3.2	550,000	17,000	55,000	450	86,000	2,100	50,000	1,900	55,000	750
18	34	2.7	550,000	22,000	47,000	1,300	80,000	1,300	80,000	1,200	8,500	520
25	35	2.7	800,000	35,000	26,000	2,800	110,000	6,000	100,000	5,500	64,000	60
February 1	34	3.3	450,000	75,000	30,000	4,000	70,000	16,000	55,000	11,000	2,500	230
8	33	3.6	800,000	8,000	60,000	400	340,000	2,000	200,000	1,100	10,000	100
15	35	3.4	650,000	43,000	30,000	250	60,000	2,500	50,000	2,000	33,000	280
22	34	3.4	390,000	17,000	24,000	900	74,000	2,600	52,000	2,000	10,000	400
29	34	3.3	550,000	13,000	40,000	100	90,000	3,400	60,000	2,500	33,000	750
March 7	35	3.8	430,000	3,400	30,000	190	140,000	2,300	75,000	1,500	40,000	70
14	38	3.1	500,000	18,000	35,000	700	170,000	5,500	120,000	4,500	25,000	550
21	38	3.0	600,000	7,500	65,000	320	180,000	2,200	140,000	1,800	55,000	360
28	42	2.5	460,000	18,000	36,000	500	140,000	5,700	95,000	4,500	25,000	700
April 4	40	3.2	450,000	8,000	60,000	1,400	140,000	3,000	80,000	2,200	40,000	240
11	42	2.4	2,500,000	37,000	500,000	6,000	160,000	8,500	90,000	4,400	10,000	1,000
18	42	1.7	1,100,000	35,000	220,000	6,000	160,000	4,300	75,000	2,000	70,000	850
25	46	2.7	600,000	100,000	70,000	2,400	150,000	7,500	75,000	2,300	46,000	800
May 2	54	3.4	450,000	2,000	60,000	200	250,000	1,000	55,000	300	55,000	55
9	48	3.1	600,000	23,000	180,000	5,500	210,000	2,200	140,000	900	25,000	400
16	56	3.0	600,000	9,000	85,000	1,200	120,000	1,800	32,000	1,600	40,000	200
23	58	2.6	1,400,000	28,000	220,000	2,400	280,000	11,000	170,000	9,000	85,000	1,000
30	62	2.7	700,000	18,000	130,000	3,800	230,000	6,000	160,000	350	64,000	800
June 6	61	2.8	850,000	34,000	100,000	3,800	190,000	4,600	150,000	3,500	85,000	850
13	68	2.5	550,000	35,000	160,000	1,500	75,000	3,200	55,000	1,500	40,000	200
20	68	2.8	630,000	32,000	120,000	3,600	110,000	4,800	60,000	1,500	8,000	62
27	68	3.0	1,100,000	13,000	120,000	1,300	210,000	5,700	80,000	300	2,800	200
Average	45	3.4	750,000	24,000	95,000	1,800	150,000	3,900	90,000	2,400	47,000	380

[a] Jackson bile media used.

The average efficiencies as measured by the per cent of bacteria removed for the whole period and for certain shorter periods, selected to illustrate the effect of different concentrations of chlorine and of fluctuating conditions of temperature, are shown in Table 18.

TABLE 18.—*Disinfection of trickling-filter effluent at Boston; summary of bacteriological results, averaged by periods, to show the effect of changes in temperature and in the amount of available chlorine.*

Period.	Temperature.	Available chlorine, in parts per million.	Per cent of bacteria removed.				
			Bacteria at 20° C.		Bacteria at 37° C.		
			Total.	Liquefiers.	Total.	Acid formers.	*B. coli.*
	° F.						
November 12 to June 27	45	3.4	96.8	98.1	97.4	97.3	99.19
November 12 to December 12	42	6.3	99.57	99.73	99.81	99.91	99.99
January 27 to March 28	36	3.2	95.8	97.7	96.6	96.4	98.5
April 27 to June 27	60	2.9	97.1	98.0	97.6	97.9	99.07

Comparison of the results obtained in the periods November 12 to December 12 and January 27 to March 28 shows that the additional bacterial removal gained by increasing the available chlorine from 3.2 to 6.3 parts per million, although it is considerable in amount, is hardly commensurate with the cost. The effect of temperature on the bacterial removal is shown in the periods from January 27 to March 28 and April 27 to June 27. The mean temperature is 36° F. in one period and 60° F. in the other, while the available chlorine is practically the same in both periods, though slightly higher during the period of lower temperature. An advantage in favor of the summer results is noticeable, and it would probably have been a little greater with exactly the same amount of chlorine. Yet the results show especially that the effect of temperature on efficiency is not great. This point is of special significance in comparing the results of chlorine disinfection with those obtained with copper. In experiments with copper, temperature has been shown to produce a marked effect; in fact, the concentration of copper must be doubled during the winter months to maintain the efficiency of the process. The bacterial removals in the several groups of bacteria recorded are nearly the same, though the removal of *B. coli* is higher in all experiments. It is probably safe to assume that the removal of the typhoid and other pathogenic organisms will be as nearly perfect as the removal noted in any of these groups. The per cent removals of organisms shown by the counts at 37° C. and by the *B. coli* results probably represent most nearly the per cent removal of typhoid bacilli.

As has been stated, the reliability of a disinfection process depends quite as much on the general evenness of the results as on the average efficiency. For that reason the per cent removal of total bacte has been computed for each of the 158 individual tests, and the resu of the calculations, given in Table 19, show that the per cent remov was between 98 and 100 per cent in over half the individual tes and that it was less than 94 per cent in only 15 per cent of the tes

TABLE 19.—*Relation between individual tests of bacterial removal and the average r at Boston.*

Per cent of total number of tests.[a]	Per cent removal of total bacteria.	
	Not less than—	Less than—
54	98	100
19	96	98
12	94	96
6	92	94
2	90	92
3	85	90
2	75	85
2	65	75
Total, 100	Average, 96.3	

[a] Number of individual tests, 158.

The number of bacteria remaining in the disinfected effluent hav been tabulated in a similar manner, in order that the bacterial quality of the final effluent may be properly understood. The results are given in Table 20.

TABLE 20.—*Relation between individual bacterial counts and the average result at Boston.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
47	100	10,000
23	10,000	25,000
20	25,000	50,000
5	50,000	100,000
3	100,000	200,000
2	200,000	250,000
Total, 100	Average, 24,000	

[a] Total number of tests, 158.

The average of the 158 individual tests of bacterial removal is 96.3 per cent, as compared with 96.8 per cent removal (see Table 17, p. 42) obtained from the average numbers for the whole period. The first figure is more nearly correct for estimating the efficiency of the process; but it is evident that the last figure, which is more commonly employed in such work, gives the average result with sufficient accuracy. The somewhat tedious calculation of the individual resul and their variations has been made only for the total bacteria; but the results suffice to show that the average per cent removal of bacteria, computed from the average initial and final counts, is practically the same as the average of the per cents calculated from the individual tests, and that there is a certain variation in the results to the extent shown. As to the other groups of bacteria studied, it is sufficient to state that similar computations with them gave practically identical results, subject to much the same deviations.

In order to study the effect of varying the time of contact with the disinfectant, samples of the trickling-filter effluent were collected from the mixing trough after the disinfecting solution had been added. After these samples had been well shaken, determinations were made of the number of bacteria remaining at the end of ten minutes, fifteen minutes, one hour, and two hours, the sample being shaken each time before withdrawing the test portion. The number of bacteria in the effluent before treatment, as determined on a separate sample, was between 250,000 and 1,000,000 per cubic centimeter; but the numbers in all tests have been converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter for more ready comparison of the results in Table 21.

TABLE 21.—*Relation between time of contact and efficiency of disinfection with chloride of lime.*[a]

Date.	Number of remaining bacteria per cubic centimeter[b] after contact for—			
	10 minutes.	15 minutes.	60 minutes.	120 minutes.
August 6	....	1,100	160	150
9	2,500	190	58	7
10	10,000	270	....	40
11	3,500	570	154	100
14	47,000	1,100	700	570
15	4,200	310	120	120
16	1,200	240	100	130
17	9,800	800	260	150
20	400,000	12,000	7,000	5,500
21	28,000	2,100	1,300	1,000
23	1,300	230	110	31
Average	50,000	1,700	950	700
Per cent of remaining bacteria	5.0	0.17	0.10	0.07

[a] Available chlorine, 5 parts per million.

[b] All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.

The rapidity of the action of the disinfectant is somewhat surprising, and it indicates that long periods of contact are unnecessary. It is evident that the greater part of the disinfection is accomplished within the first fifteen minutes, and that a contact period of one hour is probably ample for practical work. Another feature of interest in this experiment is its bearing on the character of the sediment in the disinfection tanks. It has been suggested that perhaps such sediment carries down with it large numbers of the bacteria that are recorded as being removed, though they may be still vigorous within the protecting body of solid matter. It is undoubtedly true that ordinary sedimentation tanks remove a considerable number of bacteria, and the actual removal is doubtless even greater than would appear from the data, owing to multiplication during sedimentation. But in their slow descent through the liquid, such bacteria are subject to the action of the chlorine, the supply of which is constantly renewed by the downward movement of the particles. The major portion of such sediment is suspended in the liquid for periods varying from fifteen minutes to an hour, during which time the chlorine has evidently ample opportunity to act. In the series of tests just described this sediment was included in the bacterial determinations. It is interesting to note, therefore, that the average reduction of bacteria at the end of two hours was 99.93 per cent, while the routine tests on the same days in the sedimentation tank gave an average reduction of 99.96 per cent, results practically identical. The sediment is apparently as completely disinfected as the supernatant liquid, but naturally an accumulation of sediment at the bottom of the tank would soon rid itself of chlorine and permit the multiplication of the remaining bacteria. Such secondary growth of bacteria, however, has no sanitary significance, since it has been satisfactorily shown that the pathogens do not develop in such manner outside the body.

These results demonstrate the entire feasibility of satisfactorily disinfecting trickling-filter effluents with chloride of lime, and they indicate that about 3.5 parts per million of available chlorine and a contact period of about one hour are ample for an effluent like that on which the experiments were made. A general discussion of the results in their practical application to the disinfection problem with special reference to costs is given on pages 63–70.

DISINFECTION OF CRUDE SEWAGE.

Under certain circumstances it may be necessary and desirable to disinfect the crude sewage of a community, though such a procedure would not as a rule be considered. It can never take the place of purification except by the use of excessive amounts of disinfectant; and by destroying the bacteria always present it simply delays the natural processes of reduction, allowing them to proceed at a later time, possibly after the solid matter has had time to settle to the bottom of a stream where the greatest nuisance will be caused by its decomposition. It might happen, however, that a sufficiently great dilution to preclude anaërobic action and a sufficiently swift current or tidal flow to prevent sedimentation would obviate all danger of a nuisance except from a bacterial standpoint. Such conditions are, perhaps, most nearly realized in our seaboard cities, where there may be no question of a physical nuisance, but where bacterial pollution of the harbor waters may be undesirable for various reasons.

The disinfection of crude sewage was studied because it was believed that experiments with the material might help to solve the general problem. The relations between available chlorine, amount of organic matter, and germicidal effect suggest that an excessive amount of organic matter in raw sewage might affect the efficiency of the chloride of lime treatment by combining directly with the chlorine and thus preventing its activity. The quality of the organic matter might also influence the result; for, as the organic matter of crude sewage is more readily oxidizable than that of an effluent, it might be expected to consume a greater amount of chlorine than the latter in a short time. The experiments with crude sewage were undertaken with the object of studying such features and of ascertaining the concentrations of chlorine necessary to effect a satisfactory removal of the bacteria in crude sewage, having in view both the possible disinfection of crude sewage itself and the establishment of a maximum limit of available chlorine in the treatment of effluents.

The details of these experiments differ somewhat from those of the effluent tests that have been described. In treating an effluent, sedimentation is an advantageous process by itself and can be usefully employed as an adjunct in disinfection, but in treating raw sewage, the removal by sedimentation of large amounts of organic matter in an unoxidized condition is undesirable and is not permissible in practice. In the experimental work, therefore, it was necessary to prevent sedimentation during the treatment.

A rectangular tank having a capacity of about 700 gallons was employed for the experiments. A 2-inch pipe led from the bottom of the tank to a pump with sufficient capacity to draw out the entire contents of the tank in half an hour. The outlet pipe from the pump discharged into the top of the tank, and the rapid circulation maintained in the sewage in this manner during the experiment made sedimentation of solids practically impossible. Before the beginning of the test the sewage was pumped through the system for fifteen minutes in order to insure thorough mixing; then a sample was collected for chemical and bacterial analysis, and the calculated amount of disinfectant solution was slowly poured into the inflowing stream. The force of this stream entering the tank from a height of about six feet churned the sewage thoroughly and assured rapid and complete mixing. Samples were collected at the end of the second and fourth hours for determination of the total bacteria growing at 20° C. and of the number of *B. coli*. The available chlorine employed was ten parts per million. In the first series of tests the total amount of chloride of lime was added at first, but in the second series it was added in four portions at hourly intervals. The results are tabulated in Table 22.

TABLE 22.—*Disinfection of crude sewage with chloride of lime at Boston; series 1 and 2.*[a]

Series.[b]	Temperature.	Number of bacteria per cubic centimeter.		
		Initial.	At end of 2 hours.	At end of 4 hours.
	°*F.*			
1	44	700,000	4,900	13,000
	46	260,000	220	5,700
	50	750,000	10	100
	60	600,000	620	80
	60	200,000	500	100
	60	270,000	500	100
Average	54	460,000	1,100	3,400
2	56	600,000	700	190
	60	400,000	100	70
	60	360,000	260	40
	60	460,000	14,000	340
	60	280,000	22,000	200
	60	540,000	7,000	130
Average	59	450,000	7,500	190
Number of *B. coli* per cubic centimeter; average of both series.		35,000	24	15

[a] Available chlorine, 10 parts per million.

[b] Series 1. Chlorine added at start. Series 2. Chlorine added in four equal hourly portions.

The average reduction of total bacteria in the first series was 99.76 per cent at the end of two hours, and, owing to multiplication of bacteria, 99.26 per cent at the end of four hours. In the second series the reduction in two hours was only 98.3 per cent, five parts per million of available chlorine having been added up to that time, and the addition of another five parts of chlorine brought the total reduction up to 99.96 per cent at the end of four hours. This indicates that there is a distinct advantage in adding the disinfectant in successive portions, but the increased efficiency in this case was not great, and it is doubtful whether it would generally be sufficient to compensate for the more complicated method of operation.

The figures for *B. coli* have little individual significance, but the average values indicate a removal of *B. coli* of 99.93 per cent and 99.97 per cent after two hours and four hours, respectively—values that are considerably better than those derived for the total bacteria. The results of the disinfection of crude sewage therefore agree with those obtained with the filter effluent. It is also apparent from these experiments that ten parts per million of available chlorine are ample to disinfect the crude sewage of Boston, and it is probable that even a less concentration would give satisfactory results. It is evident also that two hours is a sufficient contact period, little advantage being gained by making it longer.

April, 1908, a third series of experiments with crude sewage ade to determine the minimum amount of chlorine and of con- ime possible for satisfactory disinfection. These tests were ally like those of the first series, except that the available e was varied each day, so that on successive days it amounted , four, six, eight, and ten parts per million, respectively. On th day it was started again at two parts. In this way the of chlorine concentration was studied with as little interference sible from other variables, such as temperature and character sewage. A two-hour period of contact was given, and in ad- to the initial sample, in each test, samples were collected after hour, one hour, and two hours. The results of this series are in Table 23.

LE 23.—*Disinfection of crude sewage with chloride of lime at Boston; series 3.*

ble chlorine (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			
		Initial.	One-half hour.	1 hour.	2 hours.
	° F.				
	52	1,100,000	90,000	62,000	130,000
	58	1,600,000	320,000	470,000	870,000
	59	1,200,000	32,000	49,000	140,000
	53	900,000	47,000	16,000	42,000
	60	1,900,000	400,000	450,000	700,000
	64	1,700,000	370,000	460,000	1,000,000
	54	2,100,000	50,000	41,000	65,000
	55	1,100,000	5,000	6,500	4,400
	59	1,400,000	30,000	40,000	85,000
	58	950,000	3,400	1,100	4,200
	60	1,900,000	12,000	11,000	23,000
	64	3,500,000	33,000	26,000	80,000
	56	1,700,000	3,600	9,000	1,700
	58	1,700,000	6,500	600	6,000
	60	2,800,000	17,000	4,600	4,400
	57	1,700,000	1,700	8,400	3,900
	60	2,400,000	1,800	3,000	1,700
	64	3,300,000	14,000	11,000	18,000
	55	1,000,000	570	480	600
	60	1,500,000	3,400	160	730
	59	2,000,000	2,000	1,100	3,700
	59	1,100,000	340	170	750
	63	2,600,000	1,900	2,700	3,300
	65	2,500,000	6,300	3,300	9,500
	52	1,600,000	380	300	400
	57	610,000	200	210	200
	58	1,900,000	1,100	430	1,600
	62	1,100,000	370	800	1,100
	64	2,500,000	500	350	850
	64	3,100,000	3,500	2,300	4,800
	56	1,200,000	1,500,000	1,800,000	2,100,000

results indicate that a large amount of chlorine is consumed sewage within two hours. Two parts per million are consumed half an hour and ten parts per million are not sufficient to t the subsequent growth of bacteria. It has, however, already ointed out that such subsequent growths have no significance at the efficiency of the disinfection from the standpoint of the enicity of the sewage is measured by the maximum reduction, ndent *of any subsequent* increase.

The average initial and minimum figures and the per cent of bacteria removed for each concentration of chlorine are brought together in Table 24.

TABLE 24.—*Disinfection of crude sewage with chloride of lime at Boston; summary of results.*

Available chlorine (in parts per million).	Average number of bacteria per cubic centimeter.		Bacteria removed.
	Average initial.	Average minimum.	
			Per cent.
2	1,400,000	210,000	85
4	1,800,000	23,000	98.7
6	2,200,000	6,000	99.7
8	1,900,000	1,200	99.94
10	1,800,000	700	99.96

These experiments were not sufficiently prolonged to furnish complete data on the process, and it is not at all unlikely that at another season of the year somewhat different results might have been obtained, though it has been shown in connection with the work on effluents that the temperature effect on the disinfection itself, other conditions remaining constant, is but slight. The bacterial and chemical composition of crude sewage, however, is affected by temperature to a much greater extent than is that of filter effluents. The amount of dissolved oxygen present is an important index to the character of the sewage or the effluent in reference to its effect on chlorine; absence of dissolved oxygen in particular indicates ready oxidizability, which in turn means the rapid absorption of chlorine. It is probably true that a given amount of chlorine acting for a given time will bring about a definite reduction in the total number of bacteria, regardless of the character of the treated liquid. Unless excessive amounts of chlorine are added, however, the time of contact is determined by the character and the amount of the organic matter in the sewage; consequently the more rapidly the chlorine is exhausted by this organic matter the shorter is the time of contact and the less is the bacterial reduction. The sewage experimented with in these tests represents about an average condition in regard to reducibility, and it contained about one-half the amount of dissolved oxygen that would be found during the winter months. Results fully as satisfactory as these could doubtless be obtained during six months of the year with even less available chlorine. During the summer months, when dissolved oxygen is not present, more chlorine than is here indicated would be found necessary. The Red Bank experiments on septic sewage make it probable that a concentration of ten parts per million of available chlorine may be taken as a maximum amount during the summer.

Satisfactory disinfection of crude Boston sewage can be accomplished by adding chloride of lime in such amounts that the -

chlorine will amount to about five parts per million during six months of the year, and to between five and ten parts during the other six months, or an average amount during the year of seven or eight parts per million. The addition of the disinfectant in portions at intervals during the treatment yields results that are somewhat better than those obtained by adding the entire amount at once, but it is not probable that this advantage is commensurate with the additional complications involved.

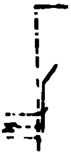
DISINFECTION OF SEPTIC SEWAGE AT RED BANK, N. J.

The successful results obtained in the disinfection of trickling-filter effluents at Boston in 1906 warranted the extension of the experiments to include a practical demonstration; and that step was made possible through the cooperation of the New Jersey State Sewerage Commission. Red Bank, a town of about 6,500 inhabitants, situated on Navesink River in Monmouth County, was selected for the tests for two reasons: The works at Red Bank were so arranged that the experiment could be undertaken at a minimum expense for new construction; and, like many other communities in that section of the State, the town was discharging partly-purified sewage into waters that shortly reached important shellfish areas. A septic sewage of rather poor quality was to be treated. Work with an effluent of higher grade had been desired, but the novelty of treating a septic sewage and the immediate practical value of the results promised to make this experiment well worth undertaking. The conditions resembled those described on pages 12–13, where it was suggested that in certain localities thorough disinfection of crude or septic sewage will go far toward accomplishing all that is needful. At least the most necessary step is thus taken first, and it is a logical first step in the gradual improvement of sanitary and economic conditions along our water fronts.

It was realized that more chloride of lime would be needed than had been used in previous experiments, but how much more was not known. The Boston results with crude sewage were not available at that time, and it was to be expected that, owing to the highly unstable character of septic sewage, even more chloride of lime would be necessary than for crude sewage. The work was started in October, 1906. During the fall the disinfection apparatus was left to the care of a local attendant, and a representative of the commission visited the works twice a week to collect samples for analysis; but mechanical deficiencies in the dosing device led to intermittent and irregular dosing, so that the results obtained were far from satisfactory, and considerable time was consumed before it was learned that more than 10 parts per million of available chlorine would be required. The work was discontinued when cold weather began, but it was resumed under more favorable circumstances in the summer of 1907. A laboratory in charge of Mr. Daniels was installed at the works, and the entire experiment was then under careful observation, for samples could be taken and examined as frequently as might be desired. The results amply justified this course. The earlier work indicated the probable strength of chlorine necessary, and developed many defects and weaknesses in the dosing apparatus, all of which were remedied. The investigations that were conducted during the summer of 1907 only are reported.

The sewerage system of Red Bank is constructed on the separate plan, with special drains to carry off rain water. On account of the sandy nature of the soil and the poor construction of the sewers considerable storm water finds its way into the sewers. The average dry-weather flow of sewage is about 265,000 gallons a day. The following description of the disposal works will be more readily understood by referring to Plate I. After entering the works the sewage divides into two streams, passing through two grit chambers, each 5 by 8 feet in plan and 3 feet deep to the flow line. The flow may be entirely diverted through either tank to allow the other to be cleaned out. From these chambers the sewage flows to the septic tank, which is circular in plan, 43 feet in diameter, with a normal depth to the flow line of 8 feet 6 inches at the periphery and 5 feet at the center, the bottom being conical. Its capacity at that depth is about 82,000 gallons, or approximately an 8-hour dry-weather flow. For the purpose of these experiments, however, it was necessary to raise the flow line throughout the system 1 foot, a change that increased the capacity of the tank to about 93,000 gallons. At the side of the tank opposite the entrance pipe the septic sewage passes out through a submerged 12-inch pipe *i*, which later divides into a Y. A branch then runs downward to the bottom of each of the filters, thence horizontally to a point beneath the center, thence upward into the filter, as shown in the sectional view. The so-called filters are two in number, and each is 12 feet in diameter. Tank *a* is 9 feet deep to the flow line, with a capacity of 7,600 gallons, and tank *b* is 8 feet 3 inches deep, with a capacity of 7,000 gallons. The tanks were originally filled with stone and brick over a false bottom and were practically strainers for the removal of suspended matter. Each filter is provided with a 12-inch overflow leading to a manhole outside the building. For these experiments the filtering material was entirely removed from both tanks, one of the outlets was closed, and a cross-connection was put in to conduct the sewage from the top of the first tank to the bottom of the second. By closing the inlet valve of the latter the entire flow was made to pass through the two tanks in series. Suitable baffles were provided, as indicated in the plan, so that the entire capacity of the tanks could be utilized to the best advantage. As thus arranged, each tank held about forty-five minutes' flow, and the efficiency of the process was tested at the end of forty-five minutes and ninety minutes.

U. S. GEOLOGICAL ATE I



ra-
ns
he
ed
he
he
ed
es-
ed
es
ch
he
a.
he
w
h
er.
et
e.
t-
as
he
s
he
a
all
of
rs
se
of
i-
ly
n
n
e
s
es

k
e
b
e
n
e

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS

Chloride of lime was used throughout the work. For the preparation of the solution two hogsheads *c* and *d* of about 240 gallons capacity each were provided, one elevated over the other. In the upper hogshead the requisite amount of bleaching powder was mixed with water and allowed to settle over night. The next morning the clear supernatant liquid was drawn into the lower hogshead. The latter was connected directly with a constant-level tank *e*, controlled by a ball cock, on which a glass ball and special fittings were necessary to prevent corrosion. The constant-level tank was connected by a flexible rubber tube with the dosing tank *f*—a box 6 by 6 inches in plan and 8 inches deep—provided with a three-sixteenth-inch orifice in one side and suspended on one end of a 6-foot lever *g*, the other end of which was connected with a large float *h* in tank *a*. Tank *a* was provided at its outlet with a 1-foot weir, by which the water level was made to vary with the flow. An increase in the flow increased the elevation of sewage in the tank, thus raising float *h* and lowering the suspended box *f* at the other end of the lever. Since box *f* was connected with the constant-level tank *e*, the effect of such change was virtually to increase the head over the orifice. In this manner the flow of the hypochlorite solution was automatically kept about proportional to the flow of sewage. The ratio was not exact, because the variation in flow with the head is not the same with a weir as with an orifice, but within the range of flows used the arrangement was quite satisfactory. By discharging the sewage from tank *a* through a submerged pipe instead of over a weir the ratio between the two flows could be kept the same at all heads. A suitable gage was erected in tank *a*, and the elevation of the sewage over the weir crest was recorded at intervals of two hours from 6 a. m. to 6 p. m., or more frequently during storms. These readings were converted into gallons, and the daily discharges of sewage were calculated from them. The night flow was approximately determined by calculations based on two sets of hourly observations extending over twenty-four hours and on the relation of these sets of data to the general averages of day flows. When the weir gage was read, readings were also taken of a gage in the hogshead *c*, calibrated to read directly in gallons. By this means the hourly flows of disinfectant solution were known at all times and could be compared with the corresponding sewage flows.

The solution of bleaching powder was run into the septic tank outlet pipe i, where it mixed with the main flow of sewage. The reated sewage then passed through the two disinfecting tanks *a* and *b* and was finally discharged into the river. The extraction of the hypochlorite was not complete in the one leaching given it. In mills where large quantities of it are extracted three successive ixiviations are customary in order to complete the extraction, but uch practice *was not feasible* here, and the sludge remaining each day in hogshead *d* was dumped into tank *a*, where it settled to the bottom and was slowly leached out by the sewage. In this way all the available chlorine was utilized.

It was necessary to have some information about the chemical composition of the septic sewage under treatment and to make certain chemical tests of the effluent. For this purpose samples of the septic sewage and of the disinfected effluent were collected daily and determinations of the oxygen consumed were made on them. These estimates gave a comparative indication of the strength of the sewage from day to day. Daily determinations of dissolved oxygen in the final effluent were also made, and the effluent was tested for free chlorine. The septic sewage never contained any dissolved oxygen, and under normal conditions the effluent would be in the same condition, but the application of free chlorine to sewage gives rise to chemical reactions, whereby free oxygen is formed. This is largely consumed in the oxidation of the organic matter, but nevertheless some free dissolved oxygen was always found in the effluent. The presence of this oxygen is of great value in the further self-purification of the sewage after reaching the river. Free chlorine was never found in the final effluent. Its presence would be highly injurious to fish life, and disinfection processes of this nature must always be so controlled that no injurious chemical can escape into the stream. In addition to the daily determinations just mentioned, composite sterilized samples were preserved and sent to Boston regularly, where they were submitted to complete chemical analysis. Regular chemical analyses of the bleaching powder and daily assays of the disinfectant solution were made.

The results of the work at Red Bank are given in the form of weekly averages in Table 25, and the relation between the individual and the average results are shown in Table 26.

TABLE 25. *Disinfection of septic sewage with chloride of lime at Red Bank, N. J.; weekly averages.*

Week ending.	Available chlorine in parts per million.	Total number of bacteria per cubic centimeter at 20° C.			Number of B. coli per cubic centimeter.[a]		
		Initial.	At end of 45 minutes.	At end of 90 minutes.	Initial.	At end of 45 minutes.	At end of 90 minutes.
1907.							
July 20	9.9	800,000	410	460	46,000	4	4
27	10.6	650,000	800	420	80,000	13	11
Aug. 3	11.5	1,800,000	550	130	40.000	21	5
10	11.4	850,000	240	140	55,000	14	2
17	13.0	760,000	2,100	1,500	70,000	30	25
24	7.3	700,000	45,000	55,000	70,000	700	600
31	7.5	1,200,000	45,000	26,000	220,000	16.000	2,000
Sept. 14	11.8	750,000	13,000	8,000	300,000	150	140
21	13.1	750,000	850	800	500,000	270	280
28	10.5	700,000	120	88	550,000	80	25
Average[b]	11.5	900,000	2,200	1,400	206,000	75	60

[a] Jackson bile media used.

[b] Exclusive of period August 19-31; temperature 55° to 58° throughout.

TABLE 26.—*Relation between individual tests of bacterial removal and the average result at Red Bank, N. J.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
84	100	1,000
5	1,000	2,000
5	2,000	5,000
6	5,000	.....
Total, 100	Average, 1,900	

[a] Total number of tests, 224.

During the period August 19 to August 31, the available chlorine was reduced to about 7.5 parts per million. A removal of the total bacteria amounting to about 95 per cent and of *B. coli* amounting to 94.3 per cent after three-quarters of an hour and 99 per cent after one and a half hours was obtained, but the individual results were very erratic, and it was apparent that an insufficient amount of chlorine was being added. The chlorine was therefore increased again to about 12 parts per million and kept there during the remainder of the experiment. The averages in the last line of Table 25 do not include the results for the above-mentioned period. The average per cent removal of total bacteria was 99.7 at the end of 45 minutes, and the corresponding *B. coli* figure is 99.96. In 90 minutes the average per cent removals were 99.8 and 99.97, respectively. It is rather striking that such results can be obtained with 12 parts per million of available chlorine, while the results are poorer and very erratic with 7.5 parts. The explanation is probably found in the character of the sewage, which was very concentrated in its raw state and had passed through a septic tank that was working vigorously. A large amount of hydrogen sulphide was contained in the septic sewage. The characteristic odor of this substance was extremely noticeable in the vicinity of the works, and the addition of chlorine to the sewage produced a milkiness, due to the liberation of free sulphur. Titration of the septic sewage in the cold with potassium permanganate, a substance less easily reduced than chlorine, indicated that enough hydrogen sulphide and other easily oxidizable substances were present to reduce instantly about five or six parts per million of chlorine. Consequently the efficient results in this experiment were in reality obtained with about six parts of available chlorine and the poor ones with about three parts.

The disinfection of septic sewage evidently requires so much chlorine that the *expense will* be considerable. It will probably *found to take twice as much* chlorine for septic sewage as for the responding crude sewage. The combination of septic action and disinfection eliminates the suspended matter and the bacteria from the sewage and in many localities would constitute a very desirable system. In practice, however, the order of the processes should be reversed. The disinfection of the crude sewage can be done in a small tank of an hour's capacity. The disinfectant should be so regulated that little or no chlorine would flow into the septic tank. Unless a considerable amount of chlorine should thus escape at one time there would be no objectionable effect on the action in the tank. There would be a great multiplication of bacteria in the tank, so that the number in the final effluent would probably be as great as in the raw sewage, and perhaps even greater. Nevertheless, the disinfection would be as effective on the pathogens as if it were applied as a final process. The subsequent development of saprophytes would have no sanitary significance and would doubtless be of real value in the subsequent self-purification of the organic matter after it had been discharged into the stream.

DISINFECTION OF TRICKLING-FILTER EFFLUENT AT BALTIMORE.

Reference was made in the history of the experiments to the cooperative arrangement between the United States Geological Survey and the Baltimore sewerage commission. In December, 1907, the sewerage commission undertook a study of disinfection methods at its Walbrook testing plant. The writer assisted in planning this work, and was consulted from time to time during its progress. The disinfection experiments were made a part of the routine work of the testing station, and they were carried out by the station staff. A complete review of this investigation, the most important and most comprehensive one on the subject ever conducted, will, it is hoped, be made by the sewerage commission in the near future. The present report has been made as brief as possible and includes only the work done before June 30, 1908.

The Walbrook testing plant, in the extreme western section of Baltimore, was built for use in investigating certain problems in connection with the disposal works now being built at Back River, the main features of which—screening, sedimentation, treatment on trickling filters, and final sedimentation—had already been decided upon. Information was specially desired as to the probable bacterial efficiency of such a process and as to the necessity for further treatment of the effluent, because the statutes of the State of Maryland require rather high bacterial efficiency. As a detailed description of the testing plant has already been published,[a] it is sufficient to state that a small section of the city was sewered and that sewage amount-

---

[a] Eng. News, vol. 57, 1907, p. 235.

› about 50,000 gallons a day was brought to the plant and
d by a system comprising a grit chamber, a septic tank, trick-
ilters, and sedimentation tanks. Trickling filters of several
s and sizes of material are employed. The sewage is rather
er than ordinary city sewage and is very fresh. The effluent
n the disinfection studies came from a filter 12 feet deep, built
shed stone ranging in size from 0.5 inch to 1.5 inches. The rate
ration fluctuated with the flow of sewage, but it averaged about
000 gallons an acre a day. The effluent was conducted to a
entation basin designed to give a two hours' flow. The disin-
it employed throughout this investigation was chloride of lime,
ved and added to the effluent in practically the same manner
Boston, as the effluent left the filter drain. The disinfecting
on and the effluent mixed during the short flow through a pipe
sedimentation basin.

nthly averages of the analyses of this effluent as it left the filter
fter disinfection and sedimentation are given in Table 27.

27.—*Chemical analyses of trickling-filter effluent at Baltimore before and after disinfection with chloride of lime and sedimentation: monthly averages.*

[Parts per million.]

INITIAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
	56	35	8.3	5.9	7.4	0.48	17	16
y	38	25	8.0	6.8	6.8	.13	17	17
	53	31	8.9	7.5	5.5	.30	19	16
	42	28	10.0	9.0	7.5	.08	21	18
	33	21	7.0	6.5	4.0	.40	20	13
verage	45	28	8.4	7.1	6.2	.28	19	16

FINAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
	38	26	8.5	6.2	7.2	0.49	16	15
y	25	17	6.8	5.8	6.8	.12	17	17
	26	17	7.9	7.1	5.5	.19	20	15
	34	20	9.6	7.6	7.9	.08	22	18
	21	16	7.0	6.5	4.0	.25	20	13
verage	29	19	8.0	6.6	6.3	.23	19	16

[a] Thirty-minute boiling method.

tial and final bacteriological samples were collected as usual.
rial counts were made three times a day for five days each week
wice on Saturday. *B. coli* determinations were made twice
The results are shown in Tables 28, 29, and 30. Table 28

gives the average weekly results; Table 29 shows the relation between the removal of bacteria in individual samples and the average removal; Table 30 indicates the relation between the number of bacteria in the individual samples and the average number.

TABLE 28.—*Disinfection of trickling-filter effluent with chloride of lime at Baltimore; weekly averages.*

Week ending—	Temperature.	Available chlorine (parts per million).		Total number of bacteria per cubic centimeter at 20° C.		Total number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.		Number of B. coli per cubic centimeter.[a]	
		Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1908.	° F.										
Jan. 4	50	3.5	......	170,000	1,600	70,000	600	8,000	107	3,800	80
11	45	2.0	......	90,000	6,500	5,500	200	3,000	58	1,700	300
18	48	1.9	......	120,000	3,300	3,100	250	2,200	165	3,400	240
25	47	2.0	......	160,000	1,900	2,000	95	900	8	1,300	45
Feb. 1	40	2.6	1.3	120,000	2,200	1,900	73	950	4	2,000	400
8	43	2.5	1.1	70,000	4,100	1,000	70	400	4	600	400
15	46	0.94	0.1	80,000	11,000	1,500	400	700	90	440	350
22	45	1.4	0.4	65,000	20,000	4,000	440	3,000	180	750	75
29	45	1.5	0.4	100,000	4,600	3,000	100	1,100	17	2,400	200
Mar. 7	46	2.0	0.6	80,000	1,000	1,400	80	900	2	1,600	150
14	47	1.7	0.4	80,000	1,700	1,000	60	500	3	1,400	150
21	49	2.0	0.4	100,000	1,300	1,100	80	600	15	2,600	180
28	52	2.1	0.3	150,000	1,700	2,400	160	1,500	3	800	200
Apr. 4	50	1.7	0.4	120,000	1,800	4,100	120	2,100	10	2,100	200
11	55	2.6	1.1	140,000	1,100	2,800	70	1,900	2	3,700	30
18	54	2.2	0.6	120,000	2,500	13,000	110	3,600	25	5,500	55
25	56	2.6	0.3	120,000	2,100	18,000	350	7,000	110	2,200	200
May 2	58	3.1	......	130,000	1,200	3,500	110	2,400	3	1,400	130
9	56	2.8	1.0	160,000	2,300	2,200	70	1,600	9	1,800	43
June 13	66	2.3	0.4	120,000	17,000	21,000	3,600	9,500	[b]730	600	100
20	67	2.3	0.8	115,000	1,300	1,800	440	300	18	3,000	300
27	67	1.9	0.1	190,000	3,700	2,900	1,100	430	0	800	400
Average	51	2.2	0.6	120,000	4,300	7,500	390	2,400	70	2,000	200

[a] Jackson bile media used.

[b] High average due to one count of 8,000.

TABLE 29.—*Relation between individual tests of bacterial removal and the average result at Baltimore.*

Per cent of total tests.[a]	Per cent of bacterial removal.	
	Not less than—	Less than—
69	98	100
14	96	98
6	94	96
0	92	94
2	90	92
2	85	90
4	75	85
1	65	75
1	40	65
1	..	40
Total, 100.	Average, 95.5.	

[a] Total number of tests, 255.

TABLE 30.—*Relation between individual bacterial counts and the average result at Baltimore.*

Per cent of total tests.[a]	Number of bacteria per cubic centimeter.	
	Not less than—	Less than—
36	100	1,000
35	1,000	2,000
8	2,000	3,000
3	3,000	4,000
4	4,000	5,000
2	5,000	6,000
2	6,000	8,000
3	8,000	10,000
7	10,000	......
Total, 100.	Average, 4,300.	

[a] Total number of tests, 255.

The average of the individual bacterial removals is 95.5 per cent. The per cent removal calculated from the average numbers in Table 28 is 96.6 per cent. The average efficiency, as in the Boston experiments, may be expressed in the latter form with sufficient accuracy, and this shorter method is employed in the other bacterial computations, by which the efficiencies in Table 31 were obtained.

TABLE 31.—*Average bacterial removal during the disinfection of trickling-filter effluent at Baltimore.*

	Per cent.
Total bacteria at 20° C	96.6
Total bacteria at 37° C	94.9
Acid formers at 37° C	97.0
B. coli[a]	90.0

The average results agree practically with those obtained at Boston. The trickling-filter effluent at Baltimore was of better quality than that at Boston and less chlorine was used. The average amount of available chlorine was 2.2 parts per million, as compared with 3.4 parts at Boston. Though the average reduction of total bacteria at both places was practically the same, the variations were greater at Baltimore, and they indicate that a somewhat greater amount of chlorine would materially improve the results. It is probable that three parts per million of available chlorine are best for treating this effluent. The *B. coli* results are not in harmony with the rest of the figures. In all the work at other places the removal of *B. coli* has been without exception better than the removal of the total organisms. Soon after the beginning of the Baltimore studies it was noticed that the removal of *B. coli*, as indicated by the bile test, was far less perfect than the general results, but efforts to discover the cause of the discrepancy were only partly successful. Complete identification of *B. coli* was carried out for a period, and the results seem to indicate that many of the positive tests after disinfection are due to the presence of an organism other than *B. coli*, which fermented the bile medium. Similar atypical results were obtained in the initial samples, but not in such large proportion. The evidence of other work under the direction of the author indicates that in these experiments the removal of *B. coli* is better shown by the removal of acid-forming bacteria than by the bile test. The results as a whole demonstrate the entire feasibility of the process and the possibility of obtaining practical disinfection at a reasonable cost.

---

[a] Jackson bile media used.

COMPARATIVE GERMICIDAL EFFICIENCIES OF CHLORINE AND SOME OF ITS COMPOUNDS.

Only a small amount of accurate data was at hand for the comparison of the germicidal efficiency of chlorine in its various forms. Accordingly, three series of comparative tests were made upon trickling-filter effluents for the purpose of obtaining such information. The results of these studies are collated in Table 32, each figure of which is the average of from three to twelve tests reduced to a uniform basis of one million initial bacteria per cubic centimeter.

TABLE 32.—*Relative germicidal properties of chlorine and some of its compounds.*

[All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.]

Series.	Source of chlorine.	Available chlorine (in parts per million).	Total number of remaining bacteria per cubic centimeter.		
			At end of 30 minutes.	At end of 1 hour.	At end of 2 hours.
I	Free chlorine	3	650	390	280
	Sodium hypochlorite	3	500	270	230
	Potassium hypochlorite	3	410	260	280
	Potassium chlorate	3	800,000	900,000	1,000,000
	Potassium perchlorate	3	750,000	1,400,000	1,800,000
II	Free chlorine	2	17,000	13,000	17,000
	Sodium hypochlorite[a]	2	15,000	6,000	6,000
	....do.[b]	2	4,600	2,100	3,400
III	Free chlorine	2	19,000	18,000	23,000
	Sodium hydroxide and chlorine[c]	2	23,000	14,000	19,000
	....do.[d]	2	22,000	12,000	18,000
	....do.[e]	2	23,000	9,000	10,000
	....do.[f]	2	19,000	7,500	8,000

[a] Electrolytic.
[b] From bleaching powder.
[c] Chlorine added thirty minutes after the hydroxide.
[d] Chlorine added twenty minutes after the hydroxide.
[e] Chlorine added ten minutes after the hydroxide.
[f] Chlorine added with hydroxide.

In series I comparison is made of free gaseous chlorine generated electrolytically, sodium hypochlorite, and potassium hypochlorite. Potassium chlorate and potassium perchlorate are also included, because they are formed in many direct electrolytic processes. The available chlorine of the two latter compounds is taken in an electrolytic equivalent sense, and would be better expressed by the term "oxidizing power." Three parts per million of available chlorine were used in all the tests of series I.

In series II comparison is made of free gaseous chlorine, potassium hypochlorite prepared from bleaching powder, and the same compound electrolytically prepared by the recombination of the products of the electrolytic cell. In this and in the next series two parts per million of available chlorine were used, because it was found that comparisons are more readily made where the disinfection is not so nearly complete.

In series III free chlorine was again used and was compared with the electrolytic hypochlorite. In this set of experiments, however, the hypochlorite was made in the sewage by adding separately the chlorine water and the sodium hydroxide. In three sets of tests the addition of the hydroxide preceded that of the chlorine by ten, twenty, and thirty minutes, respectively. The object of this procedure is to determine whether the caustic soda and the gaseous chlorine possess separately better penetrating powers than the hypochlorite does. If such were the case, formation of the hypochlorite within the solid particles of the sewage might result in more complete disinfection than could otherwise be obtained.

The results indicate plainly that hypochlorites are the most efficient germicides. Gaseous chlorine is almost as good, but in each series the free chlorine is somewhat inferior to the hypochlorite. Chlorates and perchlorates have almost no value in disinfection. The formation of these compounds in the electrolytic cell is, therefore, a total waste of energy, and should be prevented as far as possible. Production of these compounds explains in large measure the inefficiency of hypochlorite cells. Hypochlorites made electrolytically are slightly inferior to the market product, but this difference would probably be inappreciable in large-scale tests, where the conditions under which the hypochlorites are prepared are more nearly those of commercial practice. Hypochlorites of different bases evidently have the same value; the results obtained with the sodium and the potassium salts are practically identical and are similar to those obtained in practice with the calcium salt. The claim that the magnesium compound is more efficient than the calcium compound was not investigated. Hypochlorites can be made advantageously by mixing dilute solutions of free chlorine and sodium hydroxide, the products of the electrolytic cell, but the mixing should take place either in the sewage or in cold dilute solution, as otherwise chlorates and perchlorates will be formed; if the hydroxide is added a short time before the chlorine, it is removed from the solution, leaving free chlorine *uncombined and leading* to a more rapid exhaustion of the *available chlorine.*

These tests have an interesting bearing on the question of the exhaustion of the chlorine. It appears that the chlorine attacks the organic matter and the bacteria simultaneously, but that its effect on the former is a direct function of its concentration, while its germicidal effect does not bear such exact relation. If these are the true conditions, the successive addition of small portions of chlorine, or what amounts to the same thing, the addition of a substance that yields chlorine slowly, prevents the rapid reduction of the chlorine by the organic matter and prolongs the time of contact with the bacteria. In series III, Table 33, more or less of the hydrate was consumed in saponification before the chlorine was added, the amount so removed depending on the time that elapsed between the addition of the hydroxide and the addition of the chlorine. The first set of series III, therefore, represents the action of free chlorine, and the last set the action of hypochlorite, with the intermediate tests representing different proportions of the two substances. The progressive nature of the final results indicates strongly the necessity of having the chlorine combined in such form that its action on organic matter is retarded. The same effect is shown in the work on crude sewage described on pages 37–51. In the experiments reported in Table 22 decidedly better results were obtained by adding the hypochlorite in four equal portions at hourly intervals than by adding the entire amount at once. In practice the effluent to be treated should never be acid in reaction; it is probable that the addition of lime would still further decrease the rate of decomposition of the hypochlorite and increase its bactericidal efficiency.

EFFECT OF CALCIUM HYPOCHLORITE ON COLON AND TYPHOID BACILLI.

The colon bacillus has been employed in this and in other work as a convenient test organism with which to measure the efficiency of the disinfection process. For obvious reasons experiments on a large scale with the typhoid bacillus are out of the question. Consequently, a comparison was made between the relative resistance of the typhoid and the colon bacilli under controllable conditions, with the idea that in practice the effect of the disinfection process on the former could be measured by its effect on the latter. Emulsions of the two organisms in tap water were treated with hypochlorite solution, and the parallel tests with the two species were made at the same time and were kept as nearly alike as possible. The number of bacteria per cubic centimeter was determined at the end of twenty, forty, and sixty minutes, and two, four, and eighteen hours, and twelve tests of each kind were made in the same manner. The available chlorine ranged from 3.5 to 6 parts per million, averaging 5 parts. The results of the individual tests varied greatly from day to day, because, no doubt, of difference in the character of the growths and in the amounts of organic matter introduced with the organisms. Yet the average figures obtained from these twelve sets of tests probably give a fair basis for estimating the comparative resistance of the two organisms to the disinfectant. The per cent removal has been calculated and the average results are presented in Table 33.

TABLE 33.—*Comparative resistance to calcium hypochlorite of B. typhi and B. coli in aqueous emulsion.*[a]

Tests made at end of—	Removal of bacteria (per cent).	
	B. typhi.	B. coli.
3 minutes	90.5	92.0
6 minutes	98.2	98.0
1 hour	99.45	99.53
2 hours	99.60	99.70
4 hours	99.92	99.96
9 hours	99.99+	99.99+

[a] Average available chlorine, 5.0 parts per million.

The slight differences shown by the experiments on the two organisms may be attributed to experimental variations. The work is not conclusive because other strains of organisms might have yielded different results, but it indicates in a general way that *B. coli* may reasonably be regarded as test organisms in disinfection work and that the process may be expected to destroy typhoid organisms present at least as thoroughly.

It is interesting also to note that the per cent removal of *B. coli* after four hours is about the same as that recorded in the experimental disinfection of crude sewage; namely, 99.96 per cent as compared with 99.93 per cent.

PRACTICAL APPLICATIONS AND COSTS OF DISINFECTION.

The experiments that have been described were sufficiently prolonged and varied in their scope to justify the application of the chloride of lime treatment to practical disinfection on a large scale. It is not possible, however, to draw general conclusions regarding the amount of chlorine necessary for the disinfection of effluents, much less of crude sewage, because the dose is determined largely by the character of the organic and reducing matters contained in the sewage or the effluent. But the investigations have shown what may be accomplished under several conditions and they have established certain probable máximum amounts of chlorine for particular classes of sewage and effluents. They have demonstrated, for example, that trickling-filter effluents similar to those tested may be satisfactorily disinfected with three or four parts per million of available chlorine, and that such quantity will usually be sufficient to effect the removal of 95 per cent or more of the total bacteria in the effluent. If the effluent should contain only 25 per cent of the original sewage bacteria, the whole purification process would result in a removal of 98.8 per cent of the total number of bacteria. The per cent removal of *B. coli* and of typhoid organisms will be at least as high if not higher. Crude Boston sewage can be disinfected to about the same extent with from four to six parts per million of available chlorine. It may reasonably be inferred, therefore, that five parts per million of chlorine represent the maximum concentration that would ever be necessary for the disinfection of a fairly stable effluent, since no such effluent would contain as much oxidizable organic matter as the crude sewage that is treated. The septic sewage of Red Bank probably represents a maximum condition for crude sewage, because its high content of hydrogen sulphide and other oxidizable matters would probably never be exceeded in crude sewage, or at least in sewage from American cities. The disinfection of crude sewage, therefore, would require four to twelve parts per million, of available chlorine, depending on the character of the sewage and its content of oxidizable matters. It will probably be undesirable to treat septic sewage, but if such sewage should be treated, from ten to fifteen parts of chlorine, or perhaps more, would be necessary. The extreme variability of the composition of septic sewage makes it almost impossible to fix a maximum limit for the amount of hypochlorite. The amount of disinfectant required in any plant would necessarily be determined before final adoption of the plan, but these estimates will serve as useful guides, and the limits assigned include the majority of probable conditions.

No data have been obtained with effluents of higher degree of purity than those from trickling filters. The general conclusions from the work have been that the disinfectant action is a function of the chlorine concentration and of the time of contact, and that the time is determined largely by the rate at which the chlorine is consumed by the organic matter. Effluents of a better grade would probably require the same amount of chlorine, if the disinfection were to be accomplished within two hours. In the effluents with which experiments were made, the chlorine was practically consumed in two hours, but in a purer effluent chlorine would probably be left. This indicates that somewhat smaller quantities could be used with longer storage periods. A point is soon reached, however, beyond which the cost of storage is greater than the saving in disinfectant. Effluents of high degree of purity could probably be disinfected with one part of available chlorine, but a contact period of at least five hours would be required for [illegible]tory removal of the bacteria. One part is probably the minimum amount of chlorine that can be used, as the necessary time of contact increases very rapidly with decreasing concentration of chlorine.

One of the most important practical points that has been developed is the relation between organic matter, time of contact, and amount of chlorine necessary. Obviously a definite concentration of chlorine acting for a given time will bring about a definite result independent of the nature of the solution. If, however, chlorine is being consumed by the solution itself a greater amount will have to added at first in order to maintain the same average concentration. On the other hand, longer periods of contact with lower chlorine concentration are possible with the better grades of effluent. The experiments with various kinds of sewage make it possible to formulate a crude rule, which may be stated as follows: The product of the initial concentration multiplied by the time in hours required for complete reduction of the available chlorine should be about five for satisfactory disinfection, except that the contact period must not be less than half an hour in any case.

It is possible to fix within narrow limits the cost of chlorine disinfection. The cost is determined chiefly by the concentration of chlorine necessary and the related factor of contact period, and secondarily by the size of the plant. The unit used in the following summary of costs is a plant with a daily flow of 5,000,000 gallons of sewage, such a plant being the smallest that would require the entire time of an attendant, a part of whose salary may legitimately be charged to disinfection. On larger works the labor costs would increase proportionately, and on smaller works arrangements would naturally be made by which the plant could receive proper attention in connection with the regular work of the sewer or street department. The price of bleaching powder has been estimated at $24 a ton delivered at the plant; it is quoted at from $22 to $25, and a price as low as $20 is obtained on large orders by certain paper mills. The price taken is, therefore, sufficiently high to cover the cost of the moderate-sized shipments that would be required for a 5,000,000-gallon plant. A 50,000,000-gallon plant could obtain its bleaching powder for at least 10 per cent less. This bleaching powder would contain over 35 per cent available chlorine, but in order to allow for waste 33 per cent has been taken as the average figure. Labor is computed at $2 for an eight-hour day. Two hours a day—an ample allowance—are reckoned for the care of a 5,000,000-gallon disinfecting plant using 5 parts or less of chlorine. For over 5 parts the time would increase proportionately. Interest, depreciation, and other fixed charges are computed as 6 per cent of the cost of the additional works made necessary by the disinfection treatment; as the construction is chiefly masonry, but little depreciation need be allowed. In certain projects sedimentation tanks would already be available, so that the application of disinfection would not require the construction of storage tanks. For this reason the item storage tanks has been separated from the other fixed charges that include 6 per cent of the cost of mixing tanks and storage tanks for the solution, pumps, piping and connections, and suitable housing. In handling the chemicals for a plant requiring 3 parts per million or more of chlorine, some form of power mixer would be economical, and that item has been estimated. In small plants the mixture of bleaching powder and water would be settled and the solution decanted, but in the larger works the whole mixture would be used, and it would require constant stirring. The increased power item would be more than counterbalanced by the saving in tank construction. Table 34 contains a summary of the cost estimates for chlorine concentrations from 1 to 15 parts per million.

TABLE 34.—*Estimates of the cost of maintenance and operation of a plant for disinfecting sewage or effluent with chloride of lime, based on a capacity of 5,000,000 gallons a day.*

Available chlorine (in parts per million).	Time of contact (in hours).	Cost per million gallons.					
		Storage tanks.	Other fixed charges.	Bleaching powder.	Labor.	Power.	Total.
1	5.0	$0.10	$0.02	$0.30	$0.10	....	$0.52
2	2.5	.05	.04	.60	.10	....	.79
3	1.6	.04	.05	.90	.10	$0.02	1.11
4	1.2	.03	.07	1.20	.10	.02	1.42
5	.8	.03	.08	1.50	.10	.03	1.74
10	.5	.02	.16	3.00	.15	.06	3.39
15	.5	.02	.24	4.50	.20	.09	5.05

The estimates made for a 5,000,000-million gallon unit can be safely applied to larger works, and they are applicable within reasonable limits to small works that are properly managed. The cost of the tanks and of covering them would become proportionately cheaper with increased size, but this saving would be offset by the advisability of better construction and architectural embellishment. The saving due to decreased price of bleaching powder for a 50,000,000-gallon plant, using 3 parts per million of chlorine, would be about $4.50 a day, which would approximately pay for the additional chemical and bacteriological control required by a plant of such size. On very large works labor items would not increase proportionately, because most of the work would be done by machinery.

In an earlier paper[a] the opinion was expressed that the expense might be considerably reduced and efficiency increased by using electrolytic chlorine produced at the disposal works instead of bleaching powder. The relation of electrolytic processes to sewage disinfection is still unsettled, but a study of the present possibilities of such processes and experimental work with the McDonald cell and with small cells of special design have indicated that the margin of cost between the alternative methods is so slight that it hardly justifies the additional effort and the uncertainty involved in the establishment of an electrolytic plant. A brief discussion of recent developments in this field will show the reasons for this conclusion. Two general types of electrolytic process are available, in both of which the electric current is passed through a solution of sodium chloride, chlorine being liberated at one electrode and caustic soda at the other. In one type these products are allowed to recombine, forming sodium hypochlorite and certain other compounds. In the other type the products are removed from the cell as quickly as possible, the aim being to prevent their recombination. Numerous processes of the first kind have been developed, of which the Hermite and Woolfe processes have already been mentioned. The commercial preparation, called "Chloros," is made in this way. The most recent, and probably the most improved, cell of this type has recently been described by Digby and Shenton.[a] The reaction by which the hypochlorite is produced from chlorine and caustic soda in cold dilute solution is:

---

[a] *Phelps, E. B.*, and Carpenter, W. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, *1906, p. 382*; Contr. from [illegible] arch Lab., vol. 4, 1908.

$$(1)\ 2\,\mathrm{NaOH} + 2\mathrm{Cl} = \mathrm{NaOCl} + \mathrm{NaCl} + \mathrm{H_2O}.$$

In the paper just cited Digby proposes the reaction,

$$(2)\ \mathrm{NaOH} + \mathrm{Cl} = \mathrm{NaOCl} + \mathrm{H}.$$

He bases his view on the observation that the electro-chemical efficiency of the cell is over 50 per cent. Aside from the obvious impossibility that a reaction can produce at one and the same time nascent hydrogen and a strong oxidizing agent, it is apparent that reaction (1), if it were carried out completely, would yield a product containing not 50, but 100 per cent of the available chlorine initially present. The conception that this reaction represents a loss of half the available chlorine is due apparently to a mistaken idea of the term available chlorine, which, as has been explained on page 18, is really a misnomer. The fact is that the oxidizing power, or the available chlorine as ordinarily determined, of the products of reaction (1) is equivalent to twice the chlorine of the hypochlorite, or to the total chlorine present. There is, therefore, no apparent basis for the reaction proposed by Digby, which would yield twice as much available chlorine as the amount allowed by the law of electro-chemical equivalents. The reactions of equation (1) are complete only in cold dilute solutions. If the solution is hot or if it is concentrated chlorates and perchlorates are produced simultaneously. It is for this reason that the disinfectant value of these two sets of compounds was determined in an earlier part of the present investigation. It was found that they possess practically no disinfecting power and that their production in the cell represents a loss of energy. Economy in electric current demands strong salt solutions and high current densities with consequent heating of the electrolyte. Electrical efficiency is, therefore, opposed to chemical efficiency, and the problem in designing cells of this type is to balance the two efficiencies in the most economical manner. The electro-chemical equivalent of a current of one ampere is 1.32 grams an hour of chlorine, and this equivalent is not modified by the voltage. However, as the total energy employed in a process determines its cost, it is necessary to consider voltage as well as current in discussing electrolysis. In any electrolytic reaction there is a definite minimum voltage required for carrying out the reaction, and this can be computed from thermal considerations as follows: The complete reaction in the cell before the recombination of the hydroxide and the chlorine may be written,

---

[a] Digby, W. P., and Shenton, H. C. H., Surveyor, vol. 30, 1906, p. 653.

$$NaCl + H_2O = NaOH + H + Cl.$$

Substituting the heats of formation of these compounds gives

$$964 + 684 = 1118 + x, \text{ whence}$$

$$x = 530 \text{ calories (K)}.$$

Here x is the heat required by the reaction, expressed in calories (K) per gram-equivalent of the reacting substances, and its value is 530 calories. One gram-equivalent of substance is transformed with the passage of 96,540 coulombs of electricity, and one coulomb transferred under a difference of potential of one volt has an energy equivalent to 0.00241 calories. Therefore, one electro-chemical equivalent of current at a difference of potential of one volt has a heat value of 96,540 multiplied by 0.00241, or 232.7 calories. Consequently the voltage required to effect the desired reaction, which calls for a heat absorption of 530 calories per equivalent, is 530 divided by 232.7, or 2.28 volts. This is the minimum voltage with which the reaction can take place, and efficiency calculations to an energy basis must be referred to this voltage. At a difference of potential of 2.28 volts, one kilowatt gives 439 amperes, so that an output of 579 grams of chlorine per kilowatt-hour represents a process of 100 per cent efficiency on both a current and an energy basis. In practice a current at a tension of at least 4.5 volts is usually found necessary, even with strong solutions of salt and with electrodes placed as near together as possible. This factor alone reduces the energy efficiency to 5[illegible] t with perfect current efficiency. The current efficiency depends especially on the design of the cell. If there are no complicating secondary reactions during the recombination of the products it approaches 100 per cent very closely, and this is also the case in the most improved design of chlorine cell in which recombination does not take place. It is clear that the production of hypochlorite in one operation within the cell is not economical, and a review of the available information and a laboratory study of various hypochlorite cells have led to the conclusion that cells of that type can not be expected to yield much more than one-half the available chlorine that can be obtained from the same electric current by means of direct chlorine cells.

Direct chlorine cells have been developed to a high degree of efficiency, and this is the type of cell which has been considered in the present studies of sewage disinfection. The McDonald cell, which was used to some extent in this work, is giving in a regular installation in a large paper mill a current efficiency of over 80 per cent at 4.5 volts, making the total energy efficiency over 43 per cent. The most recent development is the Townsend cell, for which current efficiencies exceeding 98 per cent are claimed at a tension of 5 volts or more. The special feature of the Townsend cell is an arrangement by means of which the caustic liquor drops into a bath of oil as soon as it is formed, a step that prevents recombination. In spite of the high efficiency of such cells, it is not practicable to employ them in sewage work on account of the small margin between the market cost of chlorine and the cost of its manufacture electrolytically. This condition is due to the fact that the demand for caustic soda is so much greater than that for chlorine that the chlorine is to a certain extent a by-product and can be made into bleaching powder and sold at low cost. On the other hand, the manufacture of small amounts of caustic liquor at the disposal works does not warrant the installation of the necessary machinery for the production of pure caustic soda; consequently, without a market for this by-product, the cost of the chlorine would be the entire cost of the operation. In addition, a skilled chemical engineer who would be required would increase the cost per million gallons much more in a small plant than in a large one, while the uncertainty of the process and the increased responsibility on the sewage works both offset any slight advantage in cost which might appear in favor of the electrolytic plant. It has also been made clear in the present studies that the use of free chlorine, as contemplated in the earlier plan, is not economical and that some base should be provided for the preparation of hypochlorite. This base might be the caustic soda yielded by the process, or if a market for that by-product were available, lime could be used.

For the reasons outlined, therefore, this investigation of the possibilities of the *electrolytic processes* indicates that, contrary to earlier views, such processes are not well adapted at the present time to sewage disinfection. Nor does it seem probable that hypochlorite from cells in which the products are allowed to recombine within the cell will ever be able to replace ordinary bleaching powder.

CONCLUSION.

The main reason for disinfecting sewage lies in the probable effect of discharging pathogenic bacteria into lakes, rivers, and harbors. Any such discharge is obnoxious to the sanitarian, and when the practice of computing the cost of typhoid-fever epidemics becomes more general the cost of disinfecting sewage will not appear excessive. At present, however, the demand for sewage disinfection is confined to two conditions, namely, the possible pollution of water supplies and of shellfish beds. It has not yet been decided upon whom the responsibility rests for protecting domestic water supplies. The sanitarian recommends that rivers be kept as clean as possible and that water be filtered, but in practice distinction is made between supplies which are filtered before use and those which are not, and complete disinfection of sewage that enters streams from which supplies of the first kind are derived is still regarded as an unreasonable demand. The concensus of competent opinion requires at least, however, that, if an effluent is discharged within the region of important shellfish beds or into a stream which is used as a source of domestic water supply without filtration, such effluent shall be free from pathogenic germs. Improved standards in sanitation and improved methods of disinfection will both operate to increase these minimum requirements, but in the meantime a thorough knowledge of disinfection methods and experimentation on the improvement and the cheapening of such methods will do much to hasten their general adoption. Slow sand filtration removes bacteria in a satisfactory manner and almost totally eliminates organic matter. Under certain conditions such a result is highly desirable, but the method is comparatively costly, especially in the larger communities, and it is practically out of the question in many sections of the country.

Chemical disinfection offers a means whereby a reasonable bacterial purification may be accomplished without complete purification of the organic matter. It is in no sense a substitute for sewage purification as ordinarily understood, for, though the application of chlorine compounds to an effluent oxidizes the organic matter in it to some extent and thereby increases its stability, such improvement is only incidental. It is not in anyway comparable with the cost of treatment, and it would be unwise to attempt to obtain stability in such manner. Incidentally, however, the advantages of this increased stability are obtained, and it is probable that rapid sewage filters may be worked at somewhat higher rates and with less margin for safe operation where chlorine treatment is employed as a finishing process. Under certain conditions it may be found desirable to effect bacterial removal without organic stability; along the seacoast and possibly along some great rivers of the Middle West the dilution factor is sufficienty high to preclude the danger of physical nuisance. Under other conditions the production of a stable effluent without regard to the amount of organic matter discharged may suffice; under others the removal of suspended matter may be of prime importance. Due consideration should be given in any particular process to the character of the organic matter in the effluent, and further treatment is advisable, not only where the discharge produces, or threatens to produce, an actual physical nuisance, but wherever the self-purifying powers of the stream will be appreciably drawn upon. In other words, stability is demanded in all effluents, unless the dilution is very great, not only in relation to the local discharge, but also in relation to all the sewage or effluent that the body of water in question may receive. This much is demanded from the standpoint of physical pollution alone. If, therefore, bacterial removal is also essential, disinfection is particularly satisfactory as a finishing process, because it can now be conducted at far less cost than the cheapest form of supplementary sand filtration.

Comparison on a cost basis of the methods of chemical disinfection makes it apparent that chlorine in some form is the most efficient agent, though it must be admitted that the possibilities of heat and of certain organic compounds have not received adequate investigation. Calcium hypochlorite, or commercial bleaching powder, is by far the most satisfactory chlorine compound available. It has greater germicidal efficiency than equivalent amounts of free gaseous chlorine, chlorates, or perchlorates. It is equaled in efficiency by potassium and sodium hypochlorites, the products of certain electrolytic cells. The electrolytic production of hypochlorites or of free chlorine is not a satisfactory source of the disinfectant. The cost of such manufacture, on a scale necessarily small even at the larger sewage-disposal works, is at present so little below the cost of bleaching powder that no safe margin is left to cover the additional responsibility and uncertainty that are involved. Improved processes of manufacture may alter conditions somewhat, but the highest possible working efficiency and the cheapest power would not sufficiently reduce the costs to alter these general conclusions.

The application of 3 parts per million of available chlorine in the form of bleaching powder to a trickling-filter effluent similar to those on which experiments were made effects satisfactory disinfection. The removal of bacteria from the effluent averages over 95 per cent, making the removal for the whole purification process 98 to 99 per cent of the number in the crude sewage. The cost of disinfection ranges from $1 to $1.50 per million gallons of sewage, depending chiefly on the size of the plant. Effluents of higher degrees of purity can be disinfected at still lower cost. Five parts per million probably represents the maximum amount of chlorine required for the treatment of trickling-filter effluents of poorer quality. The results tained with the amounts of disinfectant that are specified do not, of course, amount to complete sterilization, but they may reasonably be called "practical disinfection." Considerable additional cost is required to improve them but slightly.

The disinfection of crude sewage to the same final condition requires the removal of over 98 per ce t of its total bacteria. This may be accomplished by the application of from 5 to 10 parts per million of available chlorine, the amou t depending on the character of the sewage. Such disinfection costs from $1.50 to $3.50 per million gallons.

The disinfection of septic sewage uires the application of from 10 to 15 parts per million of avail chlorine. If no further purification is required than that given by septic action and by disinfection, it is advantageous to reverse the processes by disinfecting the crude sewage before it enters the tank. The resulting development of saprophytes within the tank has no sanitary significance, and it is doubtless of great advantage in the subsequent purification of the organic matter in the stream.

The removal of *B. coli* is usually somewhat more complete than that of the total organisms. Under the conditions of a laboratory experiment, the results of hypochlorite disinfection on typhoid and colon bacilli in tap water were identical. It seems reasonable to assume, therefore, that the viability of the typhoid organism under working conditions in practical sewage disinfection is at least no greater than that of the colon bacillus and no greater than that of the sewage bacteria as a whole. Consequently the disinfection results obtained with total bacteria may, in the case of chlorine disinfection at least, be referred directly to the typhoid bacillus with assurance of reasonable accuracy.

The results obtained in this investigation are so much more favorable than any results that have been reported for similar work that comment on their accuracy and general applicability seems justifiable. The more important portions of the work have been practically duplicated under as diverse conditions as possible and by different workers. There is no apparent reason for believing that the results are not of general applicability. The reactions involved are parti ularly free from interference on the part of the mineral constitu of normal sewage, a condition which has not been f d

r has been used as the disinfectant. The sa in the present work are largely due to the fact that many little difficulties inherent in new processes have been overcome by continuous work extending over considerable periods of time, and in particular to the fact that the experiments were made part of permanent laboratory routine and were free from temporary and special characteristics which usually involve discontinuity and interruption. This routine continued week after week without interruption and without undue attention—in fact, just as it would naturally go on in practice. It is believed that the results represent what may be accomplished in practice and that they can be duplicated under working conditions on any scale which may be desirable.

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS.[a]

INTRODUCTION.

The development of modern rapid processes of sewage treatment, involving the use of coarse material, has resulted in a somewhat changed conception of the functions of sewage disposal, while the general introduction of contact and trickling filters in the newer and larger works has made it necessary to examine methods of sewage analysis from a new viewpoint. Certain hitherto important features of the analysis have assumed comparatively unimportant rôles, and new determinations have been developed on which the chief reliance is now placed. In the older methods of sewage purification, almost complete removal of organic matter and oxidation of the nitrogen were obtained, and the analytical methods employed in the control of such plants were designed to test their efficiency in accomplishing these ends. Consequently the determination of nitrogen in its different stages of oxidation and of organic matter in general were paramount. These determinations are only of minor importance in the practical control of modern rapid filters, where oxidation of nitrogen is incidental and removal of organic matter is but slight. Suspended solids, available oxygen, and the character of the effluent in reference to its stability now demand first consideration. As the production of a stable effluent is the primary function of such filters, the determination of stability becomes the most important analytical method in filter control. This point has been generally recognized, and incubation or putrescibility tests of one form or another are in general use, often at places where no further analyses are made. It unfortunately happens, however, that there are many different conceptions of what putrescibility really is and many different methods of determining it. Consequently statements of results lose much of their significance and comparisons are difficult or impossible. The present article is a review of the subject for the purpose of establishing the fundamental facts and of harmonizing current opinions. A method of determining stability, which has been in use by the writer for nearly three years, and a numerical method of expressing results, by which quantitative value is given to the test, are also presented.

---

[a] *Investigation* made at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology.

PUTRESCIBILITY.

Putrescibility, as applied to organic matter in general, implies the ability of that matter to undergo offensive putrefactive decomposition. In a strict sense putrefaction is a term applied to nitrogenous matter only, though this is a popular rather than a logical conception. Exactly what constitutes offensive putrefactive decomposition in a sewage effluent is a matter on which opinions differ. Such decomposition is always anaerobic, and it is usually accompanied by the evolution of offensive odors. These two phenomena have, therefore, formed the basis of most putrescibility tests. Some criteria of putrefaction which have been employed are: (1) Development of offensive odors; (2) formation of black sediment; (3) reduction in the amount of dissolved oxygen; (4) loss of all dissolved oxygen; (5) loss of all available oxygen, including that of nitrates and nitrites; and (6) increase in the oxygen-consumed figure. Some of these tests are based on partial reduction of the available oxygen in the effluent; others depend on the complete reduction of the available oxygen and subsequent anaerobic fermentation. The tests most commonly employed belong to the latter group, depending on the production of odor or of hydrogen sulphide, blackening of the liquid, or reduction of organic dyes. The test which depends on an increase in the oxygen-consumed figure during incubation is also in that class, because anaerobic fermentation alone renders organic matter more readily oxidizable.

These two types of test illustrate two distinct points of view which should be clearly differentiated. An effluent may be regarded as being composed of a given mass of organic matter dissolved or suspended in a definite amount of water. The water contains also a definite amount of available oxygen in the form of free dissolved oxygen, nitrites, nitrates, and possibly of other compounds. All the organic matter is oxidizable to some extent, and to that extent it serves as bacterial food. The greater the amount of organic matter and the greater its oxidizability, the greater is the absorption of oxygen from the medium. Consequently a reduction of available oxygen in the effluent during incubation is a measure both of the amount of organic matter present and of its capability of oxidation. As a small amount of readily oxidizable matter has the same effect on the result as a larger amount of more stable matter, a test of this kind indicates whether or not the organic matter consumes oxygen; but it does not show whether or not the supply of available oxygen is sufficient to prevent the establishment of anaerobic conditions. This important question of the balance between the oxygen demanded by the organic matter and the oxygen available in the liquid is taken into consideration by tests of the second kind mentioned, namely, those dependent on the establishment of anaerobic conditions. Such tests do not involve estimation of the amount and the kind of organic matter; indeed, organic matter which does not absorb any oxygen from the liquid under the conditions of an incubation test must be very highly oxidized; and, furthermore, most organic matter derived from sewage is putrescible in itself—that is, if it is stored by itself in the absence of oxygen, it undergoes putrefactive changes. The question at issue is not, however, whether the organic matter itself will putrefy, but whether the effluent as a whole will become so reduced in oxygen that putrefaction will become possible. In other words, it is simply a question of a balance between the available oxygen of the effluent and the oxygen which the organic matter will require during the incubation period. It would seem that the problem might readily be solved by determining this balance, but, unfortunately, it is not a simple matter, because the action involved is bacterial. Many attempts have been made to determine the oxygen balance analytically, but such tests answer only with very good and very bad effluents, for which an inspection of the sample would serve just as well. When there is doubt about the character of the effluent—the condition for which such information is of most value—all such analytical procedures have heretofore failed. It is evidently impossible to imitate with any degree of precision the bacterial activities that are involved. There remains, then, but one satisfactory expedient: To let the reaction proceed by itself and to note the result. But here also there are difficulties, because bacterial reactions of this sort are necessarily slow in reaching equilibrium, and the time required by a nicely balanced effluent is greater than can be allowed in routine work. Some arbitrary period of time, therefore, is usually adopted, and it is in respect to this factor that the confusion rises. If stability is to be considered a definite qualitative characteristic of an effluent, that characteristic should be determined by a test sufficiently prolonged to insure equilibrium, but such procedure is not feasible for obvious practical reasons, and it is not desirable, because it is not enough simply to know that the available oxygen is sufficient or insufficient to satisfy the demands of the bacteria that are working on the organic matter. If the available oxygen is sufficient, there is perfect stability—a definite condition; if it is insufficient, there is still stability in the quantitative sense—a relative stability determined by the relation of the available oxygen to the total amount of oxygen required by the organic matter for perfect stability. In practice the latter condition is the one usually encountered.

RELATIVE STABILITY.

DEFINITIONS.

The term putrescibility has had so many and so varied meanings in dictionaries, in popular parlance, and particularly in the minds of water chemists, that it is proposed to employ the word *stability* for that desirable quality which is the usual object of sewage purification—the transformation of the organic matter to such form that it is incapable of undergoing offensive putrefaction. This term has the added advantage of implying a positive characteristic that is acquired during purification, and it conveys a much more definite impression of the thing under discussion than the negative term *putrescibility*. A few more definitions are necessary in order to simplify the discussion. The time required to establish anaerobic conditions in an effluent which, on incubation in a closed bottle, is subject to bacterial activities producing such conditions may be called for brevity the *reducing time;* the total amount of oxygen initially present in the form of free dissolved oxygen, nitrites, nitrates, and possibly other combinations may be called *available oxygen;* the term oxygen required for equilibrium or simply *required oxygen* may be understood to express the total amount of oxygen which would be consumed by bacterial action in the effluent if the latter were supplied with an unlimited amount of oxygen and if the reaction were allowed to proceed to a condition of substantial equilibrium. An effluent of the character under discussion is not stable in the absolute sense, because its available oxygen is less than the oxygen required for equilibrium; but, of two such effluents, that one is obviously the better which contains the greater amount of available oxygen in proportion to its required oxygen. In other words, effluents of this class have a certain relative stability which is indicated by the ratio of the available oxygen to the required oxygen. This relative stability, as will be shown, can be measured by the time required to reach the anaërobic stage. The term *stability* without qualification is employed in this paper to describe that condition in which the available oxygen exceeds the required oxygen, and the term *relative stability* is used to indicate the character of the effluent in the sense suggested. A perfectly stable effluent, therefore, has a relative stability of 100 per cent.

It is apparent that time is an important element in stability tests, and that it is not compatible with the idea of relative stability to select an arbitrary period of time for establishing the line of demarcation between stability and putrescibility. It is obviously unfair to record one effluent as nonstable because it "holds up," or fails to putrefy, for only three days and to record another as stable because it "holds up" for four days. A filter might deliver during one week an effluent that would fail to pass a four-day incubation test by a narrow margin and might deliver during the next week almost crude sewage for four days and a passable effluent for three. Obviously, the first week's run would be the better and should be so recorded; but, under the present practice in many places, all the samples during the first week would be putrescible and 40 per cent of those during the second week would be nonputrescible. The first requisite, therefore, in logical study of the problem is that the time required for an effluent to reach a condition of anaerobic decomposition shall be taken as an index of its relative stability. This time element is absolutely indispensable, and any test that is adopted for the determination of relative stability should be of such a character that the length of time required for the sample to reach a given anaërobic condition may be recorded.

ESTIMATION OF THE REDUCING TIME.

Many tests have been devised to determine whether or not an effluent is putrescible, and a review of the subject with the details of the methods proposed has been given elsewhere.[a] In any determination of the time required to exhaust the available oxygen in an effluent the following conditions must be fulfilled: (*a*) The sample must completely fill the bottle, the stopper of which must be tight and must not be removed during the test; (*b*) determinations must be made at a standard temperature; (*c*) observations must be made at least as frequently as once a day. If a test is employed which necessitates opening the bottle in order to observe the condition of the sample, one bottle must be incubated for each day that the effluent is under observation. This is true for any test which depends on a chemical determination of any constituent or which depends merely on the odor developed. Obviously such tests are not well adapted to the conditions heretofore stated. A simpler procedure is one in which the anaerobic condition can be detected by the appearance of the effluent without opening the bottle. The anaerobic fermentation that occurs immediately after the complete exhaustion of the oxygen is usually accompanied by a production of hydrogen sulphide. Consequently an indicator that is sensitive to hydrogen sulphide is advantageous in detecting the beginning of the anaërobic fermentation. Fortunately delicate indicators are available for this purpose, for certain organic dyes are readily reduced to corresponding leuco-compounds under anaerobic conditions. Methylene blue is an organic dye of this character, and it is reduced to its colorless leuco base by hydrogen sulphide, alkaline sulphides, and by the commercial reducers used in dyeing. Its employment for the study of stream pollution was first proposed by Spitta,[a] and it was later more thoroughly investigated by Spitta and Weldert[b] as a test for sewage effluents.

---

[a] *Phelps, E. B., and Winslow, C.-E. A.*, On the use of methylene blue in testing sewage effluents: Jour. *Infectious Diseases*, Suppl. No. 3, 1907, p. 1.

Methylene blue, or tetra-methyl-thionin chloride, is a commercial dye of complex constitution, having the empirical composition $C_{16}H_{18}N_3SCl$. Merck's medicinal preparation is pure and it is preferable to the commercial article for sewage work. It is an extremely sensitive indicator for hydrogen sulphide and other reducing bodies, being decolorized at once in the presence of even small traces; its decolorization by bacterial action has been studied by many observers, the principal of whom are cited by Spitta and Weldert.[c] The technique of its use in testing a sewage effluent is extremely simple. One cubic centimeter of a one-tenth per cent aqueous solution of the dye is added to the effluent in a glass-stoppered bottle of 250 cubic centimeters capacity, and the sample is then incubated either at 20° C. or at 37° C. The blue color of the solution remains practically unchanged till the available oxygen contained in it has been consumed and putrefactive conditions have been established. At this stage the dye is reduced and decolorized. The time required for such decolorization is, therefore, approximately the time required for the exhaustion of the available oxygen. The dye is an indicator for what may be called the oxygen neutral point, the point at which the available oxygen becomes exhausted and anaerobic conditions are established. Some studies[d] made at the sewage experiment station confirm the earlier conclusion of Spitta and Weldert, that the end point indicated by this dye is almost exactly the desired neutral point. The order in which different forms of oxygen are reduced appears to be: Dissolved oxygen, nitrates, nitrites, sulphates, and phosphates. Methylene blue was found to change color practically at the same time as the nitrites in this series. It is readily conceivable that an indicator might possess such properties that it would be reduced before the nitrates or even before the total exhaustion of the free oxygen. Another indicator might change only after the reduction of the sulphates. The fact of this varying end point has been well shown in a recent paper by Clark and Adams.[e] Comparative incubation tests were made with 17 dyes as indicators, only 6 of which were reduced during the incubation. Arranged in the order of their reducibility these are: Indigo carmine (sulphonated indigo), methylene green, and methylene blue; and then, order not stated, congo red, methyl orange, and tropæolin. The average time computed from 26 tests for the reduction of indigo carmine was 2 days; for methylene green the average time was 2.4 days; and for methylene blue, 3.9 days. As it is of course impossible to hasten or to retard the reactions that are taking place, these differences show differences in the end point recorded by the several indicators.

---

[a] Archiv. für Hyg., 1903, vol. 46, p. 112.

[b] Spitta and Weldert, Mitteilungen aus der Königlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 6, 1906, p. 161.

[c] Loc. cit.

[d] Phelps, E. B., and Winslow, C.-E. A., On the use of methylene blue in testing sewage effluents: Jour. Infectious Diseases, Suppl. No. 3, 1907, pp. 1-13.

[e] Clark, H. W., and Adams, G. O., *Studies in incubation tests*: Jour. Am. Chem. Soc., vol. 30, 1908, p. 1037.

In the writer's experiments it was shown that the end point indicated by methylene blue is probably that point at which the free oxygen and the nitrates are practically exhausted and reduction of the sulphates is just beginning. This is understood to be the point at which anaerobic conditions are established. The work was not undertaken, however, for the purpose of determining the end point accurately, and it is possible that the end point of methylene blue is a little too far along and that either methylene green or indigotin indicates the desired point more closely. Just as it is essential in other branches of analysis to specify the indicator that shall be used in a given determination, in order to prevent confusion in comparative work, similarly it is important in this test to adopt a standard indicator as a basis of comparison. The results of all experiments thus far are in favor of methylene blue, and that dye is now widely and satisfactorily used in the laboratories of the country; consequently, its retention as a standard appears advisable, at least until further experimental evidence is available. The present series of comparative stability values is calculated on the assumption that methylene blue be used. A change in the final end point adopted would, of course, necessitate a remodeling of the computations.

THEORETICAL RELATION BETWEEN REDUCING TIME AND RELATIVE STABILITY.

The time required for complete exhaustion of the oxygen from an effluent—the reducing time—is obviously not a simple function of its relative stability; but there is a well-known theoretical relation between velocity of reaction and amount of reacting substance, from which it is possible to compute one from the other. It is a principle of physical chemistry that the velocity of a chemical reaction is a function of some power of the concentrations of the reacting substances. In the simplest cases the velocity varies directly as the concentration. The bacterial reactions that have been investigated also conform to this law,[a] and it has been, therefore, applied to the present study. The exact expression of the function need not be detailed, for it can easily be seen that this general law is approximately applicable; if one-half the work of oxidation is accomplished in one day, the availability of the organic matter as a food supply is reduced one-half, and the consequent bacterial activity on the organic matter is reduced accordingly; at the beginning of the second day food supply and bacterial activity are in the same relative proportions and the same relative amount of work is done again; that is, one-half of the remaining work of oxidation will be done during the second day. This law is expressed by the following equation:

---

[a] Chick, H., An investigation of the laws of disinfection: Jour. Hyg., vol. 8, 1908, p. 92.

Lubenau, C., Zur Säurebildung der Diphtheriebazillen: Arch. f. Hyg., vol. 66, 1908, p. 305.

Famulener, W., and Madsen, T., Die Abschwächung der Antigen durch Erwärmung: Biochem. Zeitung, vol 11, 1908, p. 186.

Nawiasky, P., Über die Umsetzung von Aminosäuren durch *B. proteus vulgaris:* Arch. f. Hyg., vol. [illegible] 1908, p. 209.

$$\text{log. } x = \text{log. } a - k^t$$

in which a is the amount of oxygen required for equilibrium at the commencement of the action, and x is the amount similarly required at the end of the time t, while k is a constant known as the velocity constant. If a grams of oxygen are required for initial equilibrium, and if x grams are required after the sample has been incubated in a tight bottle for a period of time which may be termed t days, $(a-x)$ grams of oxygen have been abstracted from the liquid by the organic matter. If the available oxygen of the liquid has just become completely exhausted at the end of t days, the value $(a-x)$ represents the amount of available oxygen originally present in the sample. It is not even necessary to know the actual amounts of oxygen, because the ratio of available oxygen to the oxygen initially required for equilibrium gives a relative stability factor that obviates the expression of the actual amounts. The ratio is

$$\frac{a-x}{a}$$

The value of this expression in terms of t and k can be found by using the logarithmic equation given above:

$$\frac{a-x}{a} = 1 - k^t$$

The second term of this equation, therefore, is equal to the ratio between the total available oxygen and the oxygen required for equilibrium, the ratio being expressed in terms of a constant and the reducing time. This ratio is the relative stability.

If a and x could be determined by analysis it would be possible to determine the value of k by a few tests. It has already been shown, however, that there is no simple chemical method of determining the amount of oxygen which is consumed by the organic matter under natural conditions. A possible method involves actual measurement of the amount of oxygen absorbed by the liquid in a time sufficiently prolonged to insure virtual equilibrium. If, however, k is determined only approximately and if a series of values for $(1-k^t)$ is obtained for all values of t, the terms of this series bear practically a constant relation to each other, even if k is varied considerably. The number expressing the relative stability is, in any case, a true index of the character of the effluent, independently of the further requirement that it shall be the absolute ratio of the available oxygen to the required oxygen. If it is not this absolute ratio it stands in constant but unknown relation to it.

An indirect method has been devised for determining the value of k with a degree of accuracy which is ample for the present discussion. For this purpose the results of 2,649 separate stability tests have been analyzed. The nature of these samples and the manner of determining the reducing time t is described on pages 78 to 80. It is sufficient to state that the reducing time was from one to twenty days in most of the tests, while many of the samples showed a relative stability of more than 100 per cent. As the samples which required a reducing time between one and twenty days had relative stabilities ranging from zero to 100 per cent, it was assumed for the purpose of approximating the value of k that one-half had values less than 50 per cent and one-half values greater than 50 per cent. Such assumption, of course, is justifiable only with a large number of observations, but it is believed that it is sufficiently accurate in the present case. Inspection of the tabulated results showed that a stability of 50 per cent was attained, at a temperature of 20° C., in almost exactly three days, thus making

$$1-k^3=0.50; \text{ or } k=0.794.$$

If this value of k is substituted in the equation before mentioned, the following values of the relative stability corresponding to the time t in days are obtained.

TABLE 1.—*Relation between reducing time and relative stability at 20° C.*

Reducing time in days. (t.)	Relative stability. ($1-0.794^t$.)	Reducing time in days. (t.)	Relative stability. ($1-0.794^t$.)
1	21	9	87
2	37	10	90
3	50	11	92
4	60	12	94
5	68	14	96
6	75	16	97
7	80	18	98
8	84	20	99

These values of relative stability are strict measures of the character of the effluent. An effluent which contains more than sufficient oxygen to establish stability should have a stability of 100; in other words, it would never reach the anaerobic stage. In practice it is *necessary* to [illegible]ne time limit to the tests and give an average stability value to all tests exceeding this limit. This value is sufficiently high to indicate the character of the effluent. On the other hand, crude sewage containing a little dissolved oxygen is completely reduced in one or two hours, or, if it contains no dissolved oxygen, decolorizes methylene blue at once; in numerical expression its relative stability is practically zero. These figures are comparative, because they may be added and divided to obtain periodical averages and the averages thus obtained are properly weighted. This is not so if the reducing times themselves are averaged. The figures are also an approximate measure of the ratio between the total available oxygen in the effluent and the amount of oxygen required for the production of stable equilibrium in the organic matter, and it is believed that the approximation is sufficiently close for ordinary purposes of interpretation.

DETERMINATION OF RELATIVE STABILITY.

INCUBATION PERIODS.

Relative stability as previously defined is a numerical measure of the relation between available oxygen and required oxygen and it is also a function of the reducing time. Some practical applications of the stability values in Table 1 remain to be outlined.

Incubation periods exceeding five days are inconvenient and probably unnecessary in practical work, but in experimental work where more detailed knowledge is desired, longer periods may be used to advantage. At the sewage experiment station, a fourteen-day period has been adopted. During the past two years tests have been made of more than 2,600 samples of trickling-filter effluents of such a quality that most of them were near the border line between satisfactory and unsatisfactory effluents. Most of them were on the safe side, but some of them were unsatisfactory for considerable periods. The results of this large number of tests, therefore, constitute an admirable basis for studying the advisability of using shorter periods of incubation. In the summary of the results in Table 2 the tests are divided first in ten groups corresponding to the different filters and the years during which the tests were made. Effluents A, B, C, and D are from trickling filters before sedimentation; E and F are the same effluents after two-hour sedimentation. The results in each group are subdivided in order to show the per cent of the number of samples that retained available oxygen at the end of stated periods. The results shown in this table have been platted and from the plats the number of samples which would have retained available oxygen after twenty days have been determined by exterpolation from a plat of the results for shorter periods of time.

TABLE 2.—*Summary of stability tests of trickling-filter effluents, showing time required to exhaust the available oxygen.*[a]

Effluent.	Period.	Number of samples tested.	Per cent of samples retaining oxygen after—									
			1 day.	2 days.	3 days.	4 days.	6 days.	8 days.	10 days.	12 days.	14 days.	20[b] days.
A	1906–7	388	91	83	75	67	58	54	48	45	42	35
B		388	93	87	81	76	67	62	58	56	53	45
C		388	97	91	86	83	78	74	72	70	70	60
F		388	97	93	91	88	84	81	77	74	73	71
A	1907–8	223	38	32	28	25	22	20	17	15	15	14
B		225	39	31	25	22	14	9	6	5	4	3
C		212	29	19	12	6	5	4	3	3	2	1
D		189	17	5	1	1	0	0	0	0	0	0
E		38	50	37	21	11	5	5	2	0	0	0
F		210	20	14	10	6	3	2	1	1	1	1

[a] Indicator, methylene blue; temperature of incubation, 20° C.

[b] Values exterpolated.

If it is assumed that in practice an incubation period of four days at 20° C. will be employed, it is possible to show from the data in Table 2 what relative stability values should be assigned to samples that retain some available oxygen after four days. Such samples may be divided into two hypothetical groups, namely, those which would have lost their oxygen between four and twenty days and those which would have retained it more than twenty days. Obviously a relative stability of 100 may be assigned to the latter because the value at twenty days is 99. An average time of ten days may be selected for the period between four and twenty days, thus making proper allowance for the decreasing number of samples, which reduce each day, and a relative stability of 90 may be assigned to that group. Between 43 and 63 per cent of the samples which passed the four-day period were reduced before twenty days. This per cent varied with the quality of the effluent, but it may be taken as 50 per cent without introducing an error of more than 5 per cent in the final result in any group. For practical purposes it may be assumed that one-half of all tests passing a four-day period of incubation will be reduced before twenty days, or in an average time of ten days, and that one-half will exceed twenty days. This gives 95 for an average relative stability value of the whole number of samples. If a four-day period of incubation at 20° C. is adopted, each sample reduced on the first, second, third, or fourth day may be recorded as having a relative stability of 20, 37, 50, and 60, respectively, and all samples retaining available oxygen after four days may be given a relative stability of 95. An individual result obtained in this manner will have but little accuracy, and when only a few tests are made, an incubation period of at least 10 days should be employed. On the other hand, when daily tests are made, the method outlined will give for monthly periods average results that are very close to the truth. Relative stability values calculated from the data in

Table 2 for the entire twenty-day period of incubation are compared in Table 3 with similar values obtained by the shorter, four-day, method. The agreement is satisfactory. If smaller numbers of tests are considered, the distribution naturally will not be so regular and greater errors will be introduced in the results calculated. In order to determine the accuracy of the proposed method, the first 776 samples of Table 2 have been subdivided into twelve quarterly groups, containing from 36 to 78 samples in each group, and the relative stability values have been calculated for these smaller groups, as shown in Table 4.

TABLE 3.—*Comparison of relative stability results obtained from the twenty-day incubation period shown in Table 2 with those calculated from a four-day period.*

Effluent.	Period.	Relative stability.	
		20-day period.	4-day period.
A	1906-7	76	77
B		81	82
E		88	86
F		86	84
A	1907-8	43	43
B		39	41
C		31	31
D		25	25
E		38	39
F		28	28

TABLE 4.—*Comparison of relative stability results obtained from smaller numbers of samples by the use of four, six, and twenty day incubation periods.*

Effluent.	Quarter.	Number of samples averaged.	Relative stability based on a—		
			4-day period.	6-day period.	20-day period.
A	1906.				
	First	37	59	59	58
	Second	73	57	53	52
	Third	59	64	61	60
	Fourth	77	89	88	88
	1907.				
	First	74	92	92	92
	Second	68	91	91	92
B	1906.				
	First	36	62	61	59
	Second	71	75	69	69
	Third	59	81	79	82
	Fourth	78	86	84	90
	1907.				
	First	75	91	90	95
	Second	69	91	90	93

The maximum error with the smaller groups is about 10 per cent, and this error can be materially reduced by basing the calculation on a somewhat longer incubation period. The second column in Table 4 shows the relative stability values calculated from a six-day period, and the maximum error in this computation is less than 5 per cent. If the greater number of the samples of a well-purified effluent retain oxygen after four days, the results with any short method of calculation will be low. Since a value of over 95 can not be obtained with this method, it is obviously impossible to provide a four or six day method which will give accurate results. If more accurate information is necessary, longer periods of incubation—perhaps as long as ten days—are advisable. It matters little, however, whether the relative stability is 95 or 99, as far as practical results are concerned, because either value represents a high degree of purification.

EFFECT OF TEMPERATURE ON THE REDUCING TIME.

It has been assumed in the foregoing discussion that the temperature of incubation is 20° C., and there are certain reasons why this temperature is better than higher ones. It probably represents more nearly than any other the average temperature of streams, and results depending on bacterial activity should be obtained near the normal temperature to which the bacteria are exposed in nature. Incubations at 37° C., for example, probably cause the development of a class of bacteria quite different from those normally at work. The most serious objection to higher temperatures, however, is the fact that certain effluents, particularly those from the rapid filters which are in such common use, contain a large amount of dissolved oxygen, frequently 8 or 10 parts per million, and this represents the greater part of the available oxygen. At 20° C. 9 parts per million of oxygen is the saturation point. The saturation point at 37° C. has not been determined, but it is not over 7 parts per million, so that there is a tendency for some of the dissolved oxygen to escape at high temperatures. Tight stoppers will not prevent the escape of this released gas unless great care is taken with them, and mercury seals are hardly adapted to routine work. It is therefore practically impossible properly to maintain the necessary saturation conditions at a temperature higher than 20° C. A variation of temperature with season would have certain advantages, but such adjustment is rather impracticable. Since results are frequently obtained at 37° C., the relation of such results to those obtained at 20° C. has been investigated and has already been reported.[a] Variable relations were found, as was expected, but the average results may be used with some degree of accuracy. It was found that the time of reduction at 37° C. was from 37 per cent to 72 per cent of that required at 20° C., and the mean of 20 determinations was exactly 50 per cent. Carefully fitted glass stoppers were used in the bottles, and ordinary precaution was taken to prevent loss of oxygen. If haste is necessary, a temperature of 37° C. will give results in about one-half the time required at 20° C. But the use of a temperature of 20° is strongly recommended whenever it is possible to employ it.

---

[a] Phelps, E. B., and Winslow, C. E.-A., loc. cit.

SUMMARY OF METHOD.

Samples should be collected in glass-stoppered bottles of 150 or 200 cubic centimeters capacity. No special precautions are necessary in collecting samples of ordinarily good effluents that are fairly high in dissolved oxygen. If the dissolved oxygen is low, precautions similar to those used in collecting dissolved oxygen samples should be observed. A one-tenth per cent solution of methylene blue, preferably Merck's medicinal quality, is used as indicator. One cubic centimeter of this solution is added to each of the samples, which are then incubated, preferably at 20° C., for four days, and observations are made at least once a day. The samples in which the methylene blue becomes decolorized are recorded as having a relative stability corresponding to the time required for reduction. Those that are blue at the end of four days are given a relative stability value of 95.

Table 5 gives the relation between time for reduction and the relative stability. Though the figures up to four days are the only ones required, the entire series up to twenty days is given for comparison. Relative figures for incubation at 37° C. also are given, but the use of that column is not recommended, except when it is absolutely necessary to use the higher temperature, or when it is desired to convert results to a standard basis of 20° C.

TABLE 5.—*Relation between relative stability and reducing time at 20° and at 37° C.*

Relative stability numbers.[a]			Relative stabilty numbers.[a]		
t_{20}.	t_{37}.	s.	t_{20}.	t_{37}.	s.
0.5		11	8.0	4.0	84
1.0	0.5	21	9.0	4.5	87
1.5		30	10.0	5.0	90
2.0	1.0	37	11.0	5.5	92
2.5		44	12.0	6.0	94
3.0	1.5	50	13.0	6.5	95
4.0	2.0	60	14.0	7.0	96
5.0	2.5	68	16.0	8.0	97
6.0	3.0	75	18.0	9.0	98
7.0	3.5	80	20	10	99

[a] s—Relative stability or ratio of available oxygen to oxygen required for equilibrium. Expressed in per cent.
t_{20}—Time in days to decolorize methylene blue at 20° C.
t_{37}—Time to decolorize at 37° C.
Theoretical relation—
$s = 100\,(1 - 0.794^{t_{20}})$
$= 100\,(1 - 0.630^{t_{37}})$

INTERPRETATION OF RESULTS.

The arbitrary tests for putrescibility now employed require no interpretation. An effluent is either putrescible or nonputrescible, according to whether it is on one side or the other of a certain line of demarcation. The fact that the dividing lines, for there are many of them, are perfectly arbitrary and have no real significance seems to have been overlooked. Fixed arbitrary standards in sewage analysis are undesirable in that they relieve the analyst of the important and difficult duty of interpreting his own results in the light of his own peculiar environment. Some general observations and rules may be stated for aid in interpretation, but it should always be borne in mind that such interpretations are dependent as much on outside conditions as on the analyses themselves. The mere statement, therefore, that 75 per cent of the samples of a tested effluent were nonputrescible has no bearing whatever on the broader phases of interpretation. These facts are well known and accepted in ordinary analytical features. The aim of the present investigation has been to place the important determination of stability on the same basis. Under this proposed method of determining relative stability an interpretation of the information in hand is rendered possible. A relative stability of 75 per cent means that the effluent in question contains a supply of available oxygen equal to 75 per cent of the amount of oxygen which the effluent will eventually require before it will have become perfectly stable. The amount of this available oxygen is estimated fairly well by the chemical determination of dissolved oxygen and nitrates. The nitrites are usually so low that they are negligible, and it is unnecessary to decide whether or not the nitrates represent available oxygen, because they have been included in the test and must be considered in the interpretation. Undoubtedly the nitrates will not be used in the stream until the dissolved oxygen of the water has been reduced to a low point. Nevertheless, the fact remains that the available oxygen in the effluent, including the nitrates, is 75 per cent of that required for equilibrium, and that the remainder must come from the water of the stream, which must also supply enough additional oxygen to replace that which may be abstracted from the nitrates of the effluent, if aerobic conditions are to be maintained. Analyses of water from the stream and estimates of the relative volumes of the stream and the effluent complete the data necessary for a full interpretation.

In general, effluents having a relative stability greater than 90 per cent may be discharged into any stream without danger of their consuming any of the oxygen of the water, because effluents of such high stability will retain oxygen indefinitely on exposure to the air.

INDEX.

A. Page.

Acids, use of, for disinfection........ 16-17
Alkalinity, effect of, on copper sulphate process........ 31
Amines process, description of........ 32-33

B.

Bacteria, fate of, in purification........ 8-12
purification by........ 7
Bacillus coli, persistency of........ 10, 12, 22-23, 36, 62-63, 72
tests for, records of........ 37
Bacillus pyocyaneus, persistency of........ 12
Bacillus sporogenes, persistency of........ 10
Bacillus typhus, persistency of........ 9, 62-63
Bacteria, sedimentation of........ 45-46
Bacteriological methods, description of........ 35-36
Baltimore, Md., experiments at........ 12, 14, 56-60
Baltimore sewerage commission, cooperation of........ 35, 56
Bengal, India, experiments at........ 24-25
Berlin, experiments at........ 19, 21-24
Birge, E. A., work of........ 35
Bleaching powder. *See* Chloride of lime.
Boston, investigations at........ 37-51
investigations at, character of........ 37-38
Brewster, N. Y., experiments at........ 27

C.

Calmette, A., experiments of........ 11
Carpenter, W. T., work of........ 35
Chemical disinfection, cost of........ 14
nature of........ 70-71
Chesapeake Bay, pollution of........ 13-14
Chloride of lime, amount needed of........ 38-39, 40, 43, 46, 48-51, 59, 63-65
amount needed of, relation of temperature to........ 43
contact period needed for........ 38-39, 45-46, 48-51, 64-65
disinfection by, cost of........ 65-70, 71-72
effect of, on colon and typhoid bacilli........ 62-63
evenness of, results with........ 43-45, 58-59
experiments with........ 38-51
penetration of solid particles by........ 22-23
price of........ 65-66
use of as disinfectant........ 18-24, 71
Chlorine, electrolytic manufacture of........ 25-29
exhaustion of........ 62
germicidal action of........ 17, 60-62
use of, as disinfectant........ 17-29, 34, 71
Chlorine, available, definition of........ 18
Chlorine cells, description of........ 69
Chlorine compounds, germicidal action of........ 60-62
Chlorine gas, germicidal action of........ 60-61
production of........ 17-18

Page.

Chloros, nature of........ 19, 67
Clark, H. W., and Adams, G. O., on reducing time........ 79
Columbus, Ohio, experiments at........ 11, 29-31
Contact-filter effluents, bacteria in........ 11
effect of chloride of lime on........ 25
effect of copper sulphate on........ 30, 32
Contact period, length of, in chloride of lime process........ 38-39, 44-45
length of, in copper sulphate process........ 30
Copeland, W. R., and Johnson, G. A., experiments by........ 29-31
Copper, use of, for disinfection........ 29-32, 34
Copper sulphate, disinfection by, relation of temperature to........ 30, 43
Cowles, R. P., work of........ 35
Crawford, H. S., work of........ 34
Crude sewage. *See* Sewage.

D.

Daniels, F. E., work of........ 7, 34, 51
Delaware River, pollution of........ 14
Dibdin, W. J., experiments of........ 19
Digby, W. P., experiments of........ 67
Disease, effect of filter purification on........ 10
Disinfection, degree of........ 24
applications of........ 63-65
conclusions on........ 70-73
costs of........ 65-70
methods of........ 15-34
classification of........ 15
See also particular methods.
necessity for........ 12-15
See also Purification; Stability.
Drinking water, purification of, responsibility for........ 11-12, 70
Drown, T. M., on electrolytic process........ 26
Dunbar and Korn, experiments on........ 19
Dunbar and Zirn, experiments of........ 19

E.

Eau de Javelle, nature of........ 19
Electrolytic chlorine processes, cost of. 66, 69-70, 71
description of........ 25-29, 67-69
Elsner and Proskauer, experiments of........ 19
Emerson, C. A., work of........ 35
Experimental investigations, account of........ 34-65
expression of........ 36-37

F.

Fermi, experiments of........ 27
Filter effluents, effect of chloride of lime on........ 25
effect of copper sulphate on........ 30-32
effect of sodium benzoate on........ [illegible]
Filtration, effect of, on bacteria........ [illegible]
Fuller, G. W., on oyster crop........ [illegible]

G. Page.

Gelatine, penetration of, by chloride of lime.. 22-23
Germany, chemical disinfection in........... 14

H.

Hamburg, experiments at.................... 19-21
Heat, use of, for disinfection.............. 15-16, 33
Hermite process, description of.............. 27-28
Hospital sewage, experiments on............ 20
Houston, A. C., experiments of............ 9-10, 12
Hypochlorites, use of, in disinfection........ 18-25

I.

Ivanoff, investigations of.................... 16

J.

Jackson, D. D., bile broth test of........... 11, 35
Johnson, G. A., experiments of.............. 11
Johnson, G. A., and Copeland, W. R., experiments by....................... 29-31

K.

Kellerman, K. F., and Moore, G. T., experiments of........................ 29
Kellerman, K. F., Pratt, R. W., and Kimberly, A. E., experiments by. 25, 31-32
Kitasato, investigations of.................... 16
Klein, E. E., experiments of............. 15-16, 33
Korn and Dunbar, experiments of 19
Kranepuhl and Kurpjuweit, experiments of. 21-22

L.

Labarraque's solution, nature of............. 19
Lillis, M. H., work of........................ 35
Lime, use of, for disinfection................ 16

M.

MacConkey, Alfred, experiments of.......... 9
McDonald Electrolytic Cell Co., aid of...... 35
McLintock, experiments of.................. 27
McRae, H. C., work of...................... 35
Marion, Ohio, experiments at............... 25
Massachusetts Institute of Technology, cooperation of............................ 34
Moore, G. T., and Kellerman, K. F., experiments of........................ 29

N.

New Jersey State Sewerage Commission, cooperation of..................... 34

O.

Ohio, experiments in....................... 25
Organic matter, effect of, on copper sulphate process.................. 31
Oxychloride process, description of.......... 28-29
Oxygen, available, definition of............. 77
Oxygen, required, definition of.............. 77
Ozone, use of, as disinfectant............... 17

P.

Pathogens, fate of, in purification............ 8-10
Permanganate of potash, use of, for disinfection............................... 32
Phelps, E. B., work of...................... 7
Pickard, experiments of.................... 9
Plainfield, N. J., e 11-12
Potassium chlorate, germicidal action of...
Potassium hypochlorite, germicidal action
Potassium perchlorate, germicidal action o
Pratt, R. W., Kimberly, A. E., and Kell
  man, K. F., experiments by..
Pritzkow, A., and Thumm, K., experim
  of...........................
Proskauer and Eisner, experiments of.....
Purification, agents of....................
  essentials of............................
  significance of term......................
  speed of.................................
    improvement in.........................
  See also Stability; Disinfection.
Putrefaction, prevention of ....
Putrescibility, arbitrary standards of......
  control of...............................
  tests of.................................

R.

Red Bank, N. J., experiments at..........
  sewage-disposal works at..............
    plate showing.......................
Reducing time, definition of...............
  estimation of....................... 78-
  stability and, relation of ....
  temperature and, relation of ....
Relative stability. *See* Stability, relative.
Rideal, Samuel, investigations of..........

S.

Sand-filter effluent, bacteria in............
  effect of chloride of lime on............
  effect of copper sulphate on............
Sand filtration, effect of...................
Schumacher, experiments of...............
Schwarz, investigations of................
Septic effluent, chemical composition of....
  disinfection of, cost of.................
  effect of chloride of lime on.. 24-25, 51-
  effect of contact filter on...............
  effect of oxychloride on................
  effect of sand filtration on............
  effect of trickling filter on............
  treatment of, by chloride of lime.......
Septic tank, effect of......................
Sewage, crude, disinfection of.............
  disinfection of, cost of..................
  effect of chloride of lime on ....
    22, 23, 26, 46-
  effect of contact filter on...............
  effect of copper sulphate on............
  effect of oxychloride on................
  effect of sand filter on.................
  effect of trickling filter on.............
  experiments on, in Germany..........
  sedimentation of.......................
  superabundance of, effect of, on stream
  treatment of, by chloride of lime.......
Shellfish beds, protection of..............
Sodium benzoate, use of, for disinfection...
Sodium hydroxide, germicidal action of....
Sodium hypochlorite, germicidal action of.
Sodium permanganate, use of, in disinfectio
Soil bacteria, purification by..............
Sprinkling filter effluent, effect of copper s
  phate on...........................

Page.
Stability, definition of........................ 77, 88
  necessity for.............................. 74
  relation of time and............... 77-78, 80-83
Stability, relative, definition of........... 77, 85-86
  determination of.......................... 83-86
Streams, purification of...................... 8, 13
Stutzer, investigations of.................... 16

T.

Temperature, effect of, on disinfection....... 43
  effect of, on reducing time............... 86-87
Thumm, K., and Pritzkow, A., experiments of.............................. 11
Tonnetta Creek, N. Y., experiments on...... 27
Trickling-filter effluents, bacteria in......... 11
  chemical composition of.................. 40
  effect of chloride of lime on............ .. 38, 46, 56-60, 63-65, 71-72
Trickling-filter effluents, effect of copper sulphate on......................... 30-31
  effect of sodium benzoate on............. 33

V.

Vibrio, persistency of......................... 21

W.

Walbrook, Md., testing plant at...... 56-57
Webster process, description of.............. 26-27
Weldon chlorine process, description of...... 17, 18
Whipple, Leyland, work of........ 35
Whitman, E. B., work of.................... 7, 35
Wollheim, H., process of.................. 32
Woodhead, Sims, investigations of........ .. 9
Woolf process, description of............ . 27
Worcester, Mass., acid in sewage of..... ... 17

Z.

Zirn and Dunbar, experiments of............ 19

O

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 226

E POLLUTION OF STREAMS BY SULPHITE PULP WASTE

A STUDY OF POSSIBLE REMEDIES

BY
EARLE BERNARD PHELPS

Investigation made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

Page.
n 5
ution by sulphite pulp waste liquor 6
l discussion 6
on of Lake Champlain 6
on of James River 6
on of Potomac River 8
on of Black River 8
e of sulphite pulp 8
od 9
d liquor 9
gester 10
ok” 11
ng and washing the stock 12
ing the stock 13
ry 15
ulp waste liquor 15
s investigations 15
t of waste per ton of pulp 18
al composition of the waste liquor 20
al nature of the organic material 21
ation of sulphite waste liquor 22
tion of sulphite waste liquor 24
tal investigations with the organic material 27
ation of crude “lignone” 28
ity of crude “lignone” 28
ons with phosphorus chlorides 28
with alkali 29
n of the sulphur in “lignone” 29
ons with aromatic amines 30
ons of the amine-condensation products with nitrous acid 31
ons with nitric acid 31
e yellow 32
ons of the amine-condensation products with nitric acid 33
r dyes 34
rcial possibilities of lignone dyes 35
..... 35
lications on stream pollution 37

ILLUSTRATION.

Page.
iagram illustrating the steps in the manufacture of wood pulp by the sulphite process 16

HE POLLUTION OF STREAMS BY SULPHITE PULP WASTE—A STUDY OF POSSIBLE REMEDIES.[a]

By Earle Bernard Phelps.

INTRODUCTION.

The pollution of streams by the waste liquors resulting from the
anufacture of paper pulp by the sulphite process constitutes one of
e most serious stream-pollution problems with which science has
deal at the present time. The seriousness of the problem is the
ect result of two factors—the tremendous volume of such waste
uors and their high content of organic matter of extremely unde-
rable character. An approximate estimate of the amount of
lphite waste liquor discharged into the streams of the United
ates in one year is given in the subjoined statement, compiled from
ta in Forest Circular No. 120, Forest Service, United States
epartment of Agriculture.

t of sulphite waste liquor discharged into streams of the United States during 1906.

	Million gallons.
Maine	560
Massachusetts	45
Michigan	175
New Hampshire	380
New York	1,000
Ohio	41
Oregon	52
Pennsylvania	217
Virginia	84
West Virginia	89
Wisconsin	540
All other States	44
	3,227

According to the above estimate, the total amount of this liquor
charged into streams throughout the country in one year is more
an three billion gallons, and when it is considered that of this
ormous amount 10 per cent by weight, or more than 2.5 billion
unds, is solid matter, mostly organic, it will be readily conceded
t the problem of its disposal is one of no small magnitude.

---

[a] This investigation was made in cooperation with the sanitary research laboratory and sewage experi-
t station of the Massachusetts Institute of Technology.

b

EAM P UTION BY SULPHITE PULP WASTE LIQUOR.

GENERAL DISCUSSION.

Though the pollution of streams by sulphite pulp waste is an obvious and serious matter in the region where sulphite mills exist, the literature contains but few references which throw any light on the actual damage caused. In Germany the regulations of the sanitary authorities are strict. Ahrens[a] states that pulp manufacturers, in spite of constant endeavor, may come into conflict with the authorities because they are not able to meet the requirements in regard to the discharge of waste waters into rivers, and he adds that many factories in Germany have actually been obliged to shut down for that reason. Sanitary officers in the United States are more lenient. This is due partly to the fact that the streams in this country are larger and the greater number of the sulphite mills are located in less densely populated regions.

POLLUTION OF LAKE CHAMPLAIN.

In some places stream pollution from this cause has been so serious as to warrant investigation. Leighton,[b] in his investigation of the pollution of Lake Champlain, made a study of sulphite pulp waste as it affects Ausable River, which he found to be a black, foul, grossly polluted stream in which the existence of fish or other forms of life is impossible. He concluded, however, that the great dilution of the river waters by those of the lake renders the pollution insignificant so far as the lake waters are concerned.

POLLUTION OF JAMES RIVER.

Levy[c] made a careful study of the effect of sulphite waste pollution on James River. The sources of pollution are at Covington, Va., about 250 miles by water above Richmond, whose public supply is derived from this stream. Levy found Jackson River, into which this liquor is discharged and which unites with the Cowpasture below Iron Gate to form the James, to be perfectly clear and colorless. The waste entering the stream first turns the water dark brown and later a purplish black. Foam is created at the outfall and wherever the stream is interrupted by falls or by rapids. This appearance can be noted for the entire distance from Covington to Richmond. Dilution is practically the only means of improvement. On th sanitary side of the question Levy considers two problems—(1) wheth the substances introduced are themselves actually injurious to health, and (2) what influences they may have on the multiplication of bacteria. The liquor itself as it enters the river is absolutely sterile, not only on account of the actual germicidal substances which it contains, but also on account of the fact that it has been subjected for about twelve hours to steam under a pressure of 80 pounds to the square inch. Its germicidal properties are shown in the following table:

---

[a] Zeitschr. angew. Chemie, 1895, p. 41.

[b] Leighton, M. O., Preliminary report on the pollution of Lake Champlain: Water-Supply Paper U Geol. Survey No. 121, 1905.

[c] Levy, E. C., Report to the water committee on the investigation of the effect of trades wa water of James River at Richmond. Richmond, 1905.

Germicidal action of sulphite waste liquor on bacteria in highly polluted water from Shockoe Creek.

[By E. C. Levy.]

Per cent, by volume, of liquor in mixture.	Number of bacteria per cubic centimeter.			Per cent of reduction (−) or increase (+).	
	At start.	After 6 hours.	After 24 hours.	In 6 hours.	In 24 hours.
0 (control)	450,000	900,000	2,300,000	+100	+ 455
1	445,000		a 7,500,000		+1,585
5	427,500	60,000	170,000	− 86	− 60.2
10	405,000	35,000	0	− 91.4	− 100
25	337,500	10	0	−100	− 100

a Plate liquefied.

The number of bacteria in the water at the commencement of the experiment is calculated from the number of bacteria present in the creek water itself (450,000). Where the reduction is more than 99.95 per cent it is given as 100 per cent. Even very small amounts of the waste liquor have an antiseptic action, but are not actually germicidal; they restrain the growth of bacteria without killing them. Such action may be harmful rather than otherwise, for in a stream receiving sewage certain kinds of bacteria eventually render the sewage harmless. It would seem that as the character of this waste is so stable it does not furnish food for bacterial growth.

Complaint is made that the water of the James at Richmond is unfit for boiler use, both on account of its corrosive action and on account of the "priming" due to vegetable matter present. Aside from the matter of actual harm, however, Levy states that the water is rendered objectionable in appearance by this waste. The dark-brown, almost black water, with its accumulation of dirty scum, is not relished by the consumer, even if he knows that it is probably safe to drink it. In a bath tub this color is very pronounced, and even in so small a quantity as a tumblerful it is decidedly noticeable. James River is practically clear for certain periods of each year, and at such periods, under normal conditions, no further treatment than mere storage would be required for furnishing satisfactory water. But during these periods, on account of the low stage of the river, the trouble from Covington is most marked. Plain sedimentation has absolutely no effect on the color; but coagulation will remove a large part of it, and Levy found not less than 3 grains of alum per gallon necessary for this purpose. He estimates that with a daily consumption of 14,000,000 gallons it would cost $75 a day for alum, which would not be required if it were not for the sulphite pollution, and states that even then the water would not be perfectly satisfactory.

Farther up the river complaints have been made that fish have been killed by the sulphite waste. The opinion is expressed that if fish are killed it is perhaps because the free oxygen, which is necessary for their life, is used up, rather than because of the presence of substances actually poisonous in themselves.

POLLUTION OF POTOMAC RIVER.

Some experiments to determine the effect of sulphite waste pollution on fish life in Potomac River are reported by Marsh.[a] He found a decidedly injurious effect on fish of different kinds in dilutions varying in strength from 1 part of waste liquor in 50 parts of water to 1 part in 200 parts of water.

POLLUTION OF BLACK RIVER.

Whipple[b] has referred to the effect of sulphite pollution on the water supply of Watertown. He states that the sulphite liquors contribute to the odor and color of the water, and necessitate the use of greater amounts of alum than would otherwise be necessary.

MANUFACTURE OF SULPHITE PULP.

In order that the character and amount of the waste liquors resulting from the manufacture of wood pulp by the sulphite process may be comprehended it will be necessary to describe, in some detail, the various operations that are conducted in a sulphite mill to convert spruce logs into paper pulp. The processes in use at the Mechanicsville mill of the West Virginia Pulp and Paper Company will be described, as they are typical of a modern sulphite mill of average capacity. Though there are naturally many variations in minor details, the essential steps are similar at all mills, so that a detailed description of the processes of one mill, with an occasional statement of important alternative methods, will serve the purpose of this discussion.

---

[a] Marsh, M. C., in Parker, H. N., and others, The Potomac River basin: Water-Supply Paper U. S. Geol. Survey No. 192, 1907.

[b] Whipple, G. C., Proc. Watertown Soc. Eng., Watertown, N. Y., 1906.

THE WOOD.

Spruce and hemlock are the woods used almost exclusively for the manufacture of pulp by the sulphite process. The logs are either barked by hand in the woods before seasoning or by machinery at the mill. Machine barking necessitates cutting the log into 2-foot lengths; in hand work 4-foot lengths are used without further cutting. Machine barking also causes some waste of material through cutting too deeply into the log. Some measurements of logs barked by machinery show that the original circular section of the log had been changed to that of a circle minus 6 small segments, the area of the segments being found to be 18 per cent of that of the original circle. All logs are carefully inspected at the mill, and those in which there is evidence of decayed portions or unremoved bark are rejected. Subsequently a man removes the bark and decayed places from these imperfect logs with an ax. The logs are thrown into a large tank of hot water to loosen the ice, dirt, and sand which have adhered to them. They then pass through scrubbers, in which a powerful spray of water removes all the sand and cinders. They are then ready for the chipper. This machine consists essentially of three knife blades in a rapidly revolving vertical steel disk. One end of the log is pressed against these blades at an angle, and in a few seconds the log is reduced to chips. The resulting fragments are then run over screens to separate them into three portions. Everything that passes through a ¼-inch mesh is discarded. This chip dust is at present practically a waste product, though it is used to some extent for packing ice and for bedding horses. A half-day test at the Mechanicsville mill showed that 1,375 pounds of chip dust, or about 2.7 per cent of waste, resulted from chipping 17 cords of wood. The chips which do not pass through a 1-inch mesh are next separated and passed through a machine known as a shredder. This machine, working on a novel principle, crushes the large chips into shreds and separates the good wood from the knots to a large extent. The shredded mixture is then "floated" over a long water tank, in which the knots, by virtue of their greater specific gravity, sink to the bottom. The separation here is almost complete, and the removal of the knots at this time is of great benefit, as they interfere seriously with subsequent operations. The middle portion of the chipped mixture, which is retained on a ¼-inch screen and passes through a 1-inch screen, goes directly by belt conveyors to the storage bins over the digesters, as does also the floated portion of the shredded chips after a second screening. The chips are now ready for the digester.

THE ACID LIQUOR.

The solution of chemical reagents used in the digester to dissolve out of the wood all intercellular and other noncellulose matter consists essentially of calcium and magnesium bisulphites with an excess of free sulphurous acid. It is made by passing sulphur dioxide through a suspension of milk of lime made from dolomitic lime, or through towers of limestone over which water is trickling. The former process is in most general use in this country. A suspension of slaked lime (milk of lime) is made, having a strength of about 1.2° B.—that is, about 1.3 per cent $Ca(OH)_2$. Gaseous sulphur dioxide is prepared either by roasting pyrite or by burning sulphur directly in specially designed burners. The gases are passed through lead pipes submerged in large tanks, through which cold water is running, as it is essential to keep the absorption apparatus as cool as possible. The cooled gas next goes into a tank of milk of lime, which is nearly saturated by allowing the gas to enter at the bottom and to bubble up through the liquid. The unabsorbed gas is conducted from the top of this tank to the bottom of a second tank filled with fresh milk of lime, where the absorption is completed. The residual gases then pass to the pumps, which maintain a partial vacuum in the tanks and insure a constant flow of gas. During absorption the contents of the tank are constantly stirred. When the acid liquor in the first tank is of the requisite strength, as shown by analysis, it is pumped into the acid storage tanks, the second tank is emptied into the first, and fresh lime is added to the second. The process of absorption is then repeated. The composition of the acid liquor varies in different mills and even in the same mill from time to time as the quality of wood varies. A specimen analysis of the liquor, expressed in the mill terms, showed free sulphur dioxide, 2.5 per cent; combined sulphur dioxide, 1.1 per cent; a total of 3.6 per cent. "Free sulphur dioxide" is the total acidity of the solution expressed as SO_2. It is therefore the free dissolved gas plus one-half the sulphur dioxide present as bisulphite. The "combined sulphur dioxide" represents the rest of the bisulphite radicle. The actual composition of the liquor is therefore as follows, the total base being regarded as calcium:

Analysis of sulphite liquor.

	Per cent.
Calcium (Ca)	0.7
Sulphur (S)	1.8
or, in combination—	
Calcium bisulphite ($CaH_2(SO_3)_2$)	3.5
Dissolved sulphur dioxide gas (SO_2)	1.4

For one charge of a digester of average dimensions, 12.8 by 34 feet, producing about 7 tons of dry pulp at each "cook," 16,000 gallons of acid liquor are used.

THE DIGESTER.

The digester consists of an upright steel cylindrical shell with a conical bottom and a nearly hemispherical top, lined with lead, within which is another lining of resistant glazed brick, pointed with a special mortar. Older forms of digesters have concrete linings. The inside dimensions of a digester of average size are, diameter 12.8 feet, total height 34 feet, and its capacity is about 2,700 cubic feet.

THE "COOK."

About 12 cords of wood chips are first placed in the digester, and then about 16,000 gallons of the acid liquor are run in, filling the digester within 6 feet of the top. The shell is then closed tightly and steam is admitted. The contents are brought rapidly to boiling temperature and then the pressure is raised gradually to about 65 pounds, two hours being consumed in this heating. During the next two hours the pressure is increased more slowly to about 80 pounds. At this point the digester is full of liquor, the water condensed from incoming steam having completely filled the space which was left at the time of filling. In order, therefore, to add more steam it is necessary to "relieve." This process consists in allowing the liquor slowly to escape from the top of the digester as steam enters at the bottom. This relief liquor is strongly acid, and as a rule is returned to the acid-liquor tanks to be used again. There is some objection to such recovery of the relief, because it is rather dark colored and is apt slightly to color the next "cook." The temperature is carefully noted and frequent analyses of the liquor within the digester are made during the "cook," especially during the last two hours. Small samples for analysis are drawn from a tap in the side of the digester near the top. They are examined for total sulphur dioxide and the color and odor are noted. If in the opinion of the attendant the reaction is proceeding too fast, the incoming steam and the relief are both shut off and the "cook" is "held." It is intended to complete the "cook" in about six hours. Nearly at that time the sulphur dioxide content begins suddenly to fall, the color becomes darker, and a peculiar characteristic odor develops. The reactions at that time are proceeding very rapidly and the charge must be blown immediately or a dark-colored stock will result. The skill of the operator is here well shown in bringing about this rather sharp end point at almost the exact time desired, six hours. A large blow-off valve is then opened at the bottom of the digester and its entire contents are blown under full pressure into the blow pit, which is a large covered wooden tank, 22 feet in diameter and 20 feet deep, provided with a large air shaft for the escape of the steam and gases. Opposite the end of the pipe leading from the digester there is a bronze baffle plate, against which the contents of the digester are thrown with great force. The pit is provided with a false bottom and the liquor is rapidly drained off. It is essential at this point to remove all the acid liquor as rapidly as possible. After the blowing the liquor darkens rapidly from a light-garnet shade to nearly black, and its retention in the pulp results in a dark-colored product. About 15,000 gallons of wash water are added as soon as possible and drained off. A second washing is then *given with the* same amount of water, when the drains are cl l, more water is added, and the stock is ready to be pumped to storage tanks. A small amount of the acid liquor is taken out during the "cook" as relief, but the principal part of it is discharged at the end of the "cook," constituting the sulphite pulp waste liquor.

SCREENING AND WASHING THE STOCK.

The two processes of screening and washing the stock are carried on imultaneously, and can best be described together. The stock is pumped from the blow pit into storage tanks, from which it is pumped as fast as needed into an elevated tank, flowing thence to the screens and the washing machinery. It first passes through a long revolving cylindrical screen, slightly inclined from the horizontal and provided on the inside with a continuous worm-shaped vane. This screen is very finely meshed, and its function is to remove a large part of the water from the stock. Next the stock passes into a similar cylinder with rectangular meshes about one-fourth of an inch wide and 1 inch long. The wood fiber is washed through these meshes by the aid of a stream of water playing from above. All knots and undigested chips are retained in this screen, collected at its open end, and measured, the amount and character of the undigested portions being regarded as a valuable criterion of the care with which the preceding processes have been conducted. On the average, there will be about 4 cubic feet of this material per "cook," or a little over half a foot per ton of dry pulp. The stock passes from these screens to the settling tanks or "rifflers," long troughs about 6 feet wide and 2 feet deep, provided with baffles on the bottom for the retention of sediment. The object of the tanks is to remove by sedimentation any sand or grit which may have gained access to the stock from the machinery or otherwise. The stock is now ready for the final screening, by which it is separated into marketable stock and tailings. The tailings from the first screening process are generally run through a second screen and a little good fiber is saved in that way. The final tailings are passed over a wet machine and felted into low-grade pulp, which is sold for use in the manufacture of leather board. The screened pulp also is passed over a wet machine, which is essentially a revolving screen that separates the bulk of the water from the pulp, leaving the latter in a rather thick sheet. If the pulp is to be sold or used as unbleached pulp, it is taken from the wet machine at this point, passed between large wooden rollers, and finally removed in the form of thick she of wet pulp. If it is to be bleached, it is removed mechanically fr the rolls of the wet machine, mixed with a large volume of water, conducted to the bleach tanks.

BLEACHING THE STOCK.

The unbleached pulp as it comes from the wet machine has a very slight brownish color, although it appears pure white to the inexperienced eye. If such pulp is made into paper, however, it is likely to darken rapidly with age and drying, so that pulp for high-grade papers must be bleached with chloride of lime. Commercial chloride of lime, or bleaching powder, consists mainly of calcium hypochlorite, and it is made by passing free chlorine gas over quicklime. The trade name, chloride of lime, is therefore a misnomer. A typical analysis, by Wagner,[a] of bleaching powder of good quality is given herewith:

Analysis of chloride of lime.

Calcium hypochlorite ($2CaOCl_2+H_2O$)	82.65
Calcium carbonate ($CaCO_3$)	.95
Calcium chloride ($CaCl_2$)	.44
Calcium hydrate ($Ca(OH)_2$)	6.80
Water (H_2O), free	9.82
	100.66

Inasmuch as the chlorine alone of the hypochlorite is available for bleaching purposes, a sample of bleaching powder having the above analysis would contain 43 per cent of "available" chlorine and would be called a 43 per cent bleach. The product on the market seldom contains so much chlorine as that, good grades in this country running from 35 to 40 per cent available chlorine.

The bleaching powder, or "bleach," as it is called in the mill, is received in large iron casks, each holding about 600 pounds. They are emptied into a mixing tank with approximately 3 gallons of water to a pound of bleach. Generally, an ordinary tank provided with a rotary agitator is used for this mixing, but at the Mechanicsville mill an improved mixer is in service, which appears to be very efficient. The tank is conical in shape, about 15 feet high and 10 feet in diameter at the top, tapering to a point at the bottom. A centrifugal pump with a 3-inch discharge is near the tank at its bottom level. This pump withdraws the liquid mixture from the bottom of the tank and discharges it horizontally into the upper part in a direction tangential to the periphery. Circulating the liquor through the tank in this manner produces an immense vortex, so that, although the liquor whirls about the sides of the tank to the level of the inlet, one can look down into this vortex almost to the bottom of the tank. This process accomplishes a thorough mixing of bleach and water in a comparatively short time. The mixture then flows into a large brick settling tank and is allowed to settle until a clear liquor can be decanted. This liquor is tested for strength with a Baumé hydrometer and is mixed with the proper amount of a weak bleach extract to give it the required strength of about 3° B. This weaker solution is made by a second extraction of the sludge or "grout" remaining after the first decantation. The grout is usually strengthened by the addition of a small amount of fresh bleach, agitated with a fresh supply of water, and again submitted to sedimentation. The liquor obtained constitutes the weak bleach mentioned above, while the sludge remaining, the "second grout," is agitated a third time with fresh water and again settled. The third lot of supernatant liquor constitutes the water used in the first extraction of a new lot of bleach; the "third grout" is a waste product. Reference to the analysis already given will show that it consists essentially of calcium hydrate, with more or less carbonate of calcium and other impurities derived from the original lime from which the bleaching powder was prepared.

---

[a] Wagner, R. von, Manual of chemical technology; trans. from 13th German ed. by Sir William Crookes, New York, *reprint of 1904, p. 360.*

The bleach solution of about 3° B. is mixed with pulp in the proportion of about 30 gallons of solution to 100 pounds of pulp.[a] The mixture is passed successively through a series of tanks, eight in number, in which it is brought to and maintained at a temperature of about 100° F. and is mechanically stirred. Tests of this mixture are constantly being made as it passes from each tank to the next, and additional bleach solution is added as required, the processes being so regulated that, after the complete treatment, requiring about six hours' time, the pulp will be satisfactorily bleached and the bleach will be exhausted as completely as possible. It is next necessary to wash out of the pulp mixture the residual bleach and the calcium chloride resulting from the process. This is accomplished by first passing the stock under a series of washers. A washer is essentially a frame, in the form of an eight-sided prism, covered with fine-meshed copper gauze, and mounted on a horizontal axis, so that it is about half submerged in the pulp. It rotates slowly in the direction of the moving stream of stock, and as the water passes through the gauze it is collected in buckets suitably arranged within, elevated to a position above the center line of the box, and discharged through a side outlet. By this means a considerable volume of water is separated from the stock. Fresh water is admitted after each treatment and the washing is repeated several times, after which the washed stock is passed over a wet machine as previously described. It is then either pressed into sheets of wet pulp or, if it is to be used at once in the mill, is removed from the rolls by a stream of fresh water and run directly to the paper mill.

---

[a] All references to pulp in these processes are to the actual weight of air-dry pulp in the mixture, though the pulp is always mixed with a considerable amount of water throughout the process of manufacture.

SUMMARY.

The various processes described in the foregoing pages have been arranged for convenient reference in diagrammatic form in Plate I. The raw materials that enter into the process are shown along the top line of the diagram in capitals. They are wood, lime, sulphur (or pyrite), bleaching powder, and water. Arranged vertically at the left is a list of the waste and by-products of the process, namely, bark, sawdust, knots, sulphite waste liquor, sand and grit, and sludge or grout from the bleach-solution tanks. Much of the water used in the later processes is returned and used for washing the freshly cooked pulp, so that practically the only liquid waste is the waste acid liquor and the first wash waters, these together making up the sulphite waste liquor. At the bottom of the diagram the finished products of the process are shown, namely, low-grade unbleached pulp and bleached sulphite pulp. Disposal of the grout involves no serious difficulties. It is usually discharged into low-lying fields or into artificially constructed basins, where it is converted into compact masses of carbonate of lime. The small amount of chip dust is readily used in ice houses or as a bedding material for horses. The bark if removed at the mill is either burned or given away for fuel, though it is generally more economical to have the barking done before shipment. In the study of stream pollution, therefore, consideration need be given only to the combined waters resulting from the digestion of the chips and the subsequent washings of the pulp—that is, the liquor here called the sulphite pulp waste liquor.

SULPHITE PULP WASTE LIQUOR.

PREVIOUS INVESTIGATIONS.

This waste, arising as it does from an industry involving elaborate chemical methods and necessarily employing skilled paper-mill chemists, has probably received more careful and systematic study than any other waste product of the present day. A prize of 10,000 marks was offered in Germany in 1894 for the best method of preventing the pollution of streams by sulphite liquor, but it still remains unawarded. Scores of processes for utilizing or purifying the waste have been patented in Germany, England, and the United States, but none of them has been sufficiently successful to relieve, in any noticeable degree, the burdensome situation. Technical literature contains reports of exhaustive researches on the constitution of the organic substances found in this liquor, but there is no satisfactory agreement on this point. No more striking commentary on the difficulty of the problem can be made than the bare statement that, in spite of all these *researches*, the substance is still classed as a waste product. According to Cross and Bevan,[a] who summarize a paper by H. Seidel,[b] no satisfactory application of this by-product has yet been evolved. Evaporation and combustion involve losses of sulphur.[c] A more complete regeneration of the sulphur has been the subject of a series of patents.[d] The process of V. B. Drewson[e] consists in heating with lime under pressure, yielding calcium monosulphite. The sulphite is redissolved as bisulphite by treatment with sulphurous acid. This process is relatively costly, and yields necessarily an impure lye. It has been proposed to employ the product as a foodstuff both in its original form and in the form of benzoate;[f] but its unsuitability is obvious from its composition. A method of destructive distillation has been patented. Seidel,[g] however, found on investigating the process that the yield of useful products is much too low for its economical development. Fusion with alkaline hydrates for the production of oxalic acid[h] is also excluded by the low yield of the product. The application of the liquor to tanning purposes[i] appears promising from the fact that 28 per cent of the dry residue is removed by digestion with hide powder, but this application has been investigated without practical success. Various probable uses are suggested by the viscosity of the evaporated extract, but as a substitute for glue it has proved of little value. It is also used to some extent as a binding material in the manufacture of briquets and as a substitute for gelatine in the petroleum industry. Cross and Bevan[j] and Mitscherlich[k] precipitate a compound of the lignone complex and gelatine by adding a solution of the latter substance to the sulphite waste liquors. The compound is redissolved in weak alkaline solutions and employed in this form for engine-sizing papers. Ekman has patented a process[l] for "salting out" the lignone sulphonates, the product being resoluble in water and the solution having some of the properties of a solution of dextrin. Owing to its active chemical properties this product, "dextron," has a limited capability of being substituted for dextrin. The suggestion to employ the evaporated extract as a reducing agent in indigo dyeing and printing has also proved unfruitful. Seidel's application of the soda salt of the lignone sulphonic acid as a reducing agent in chrome-

---

[a] Researches on cellulose 1895 1900 p. 150.

[b] Zeitschr. angew. Chemie 1900.

[c] German patents Nos. 74030 and 83438; also Seidel and Hanak, Mitt. Techn. Gew. Mus., 1898.

[d] German patents Nos. 40308, 69892, 71942, 78306 and 81338.

[e] German patent No. 67889.

[f] German patent No. 97935.

[g] German patent No. 45951.

[h] German patent No. 52491.

[i] German patent No. 72161.

[j] British patent No. 1548 1883.

[k] German patents Nos. 93944 and 93945.

[l] German patent No. 81643.

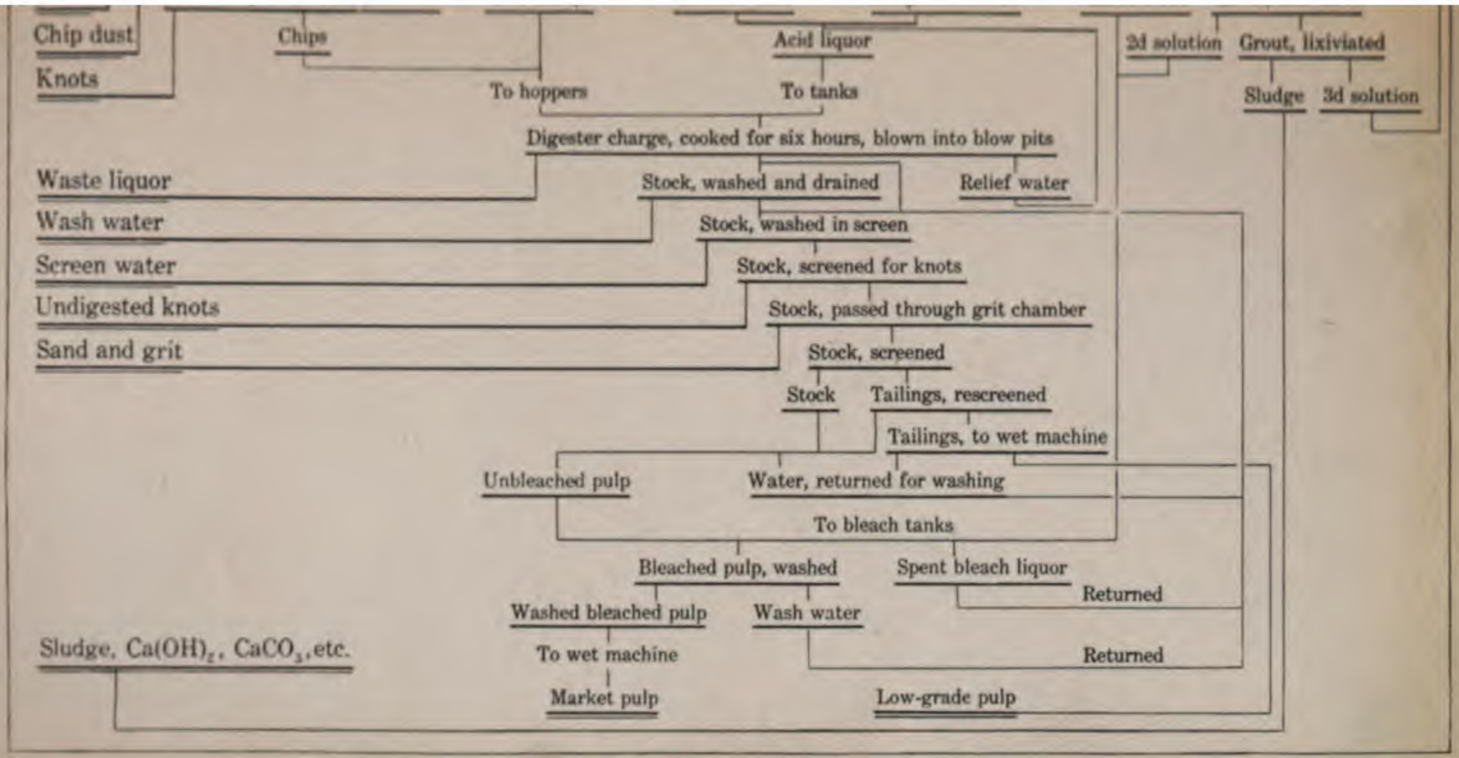


DIAGRAM ILLUSTRATING THE STEPS IN THE MANUFACTURE OF WOOD PULP BY THE SULPHITE PROCESS.

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS.

mordanting wool and woolen goods[a] is more successful in practice, and its industrial development shows satisfactory progress. The product is known as "lignorosin." In another place, however, Cross and Bevan[b] comment on this process by calling attention to the fact that such use for a by-product, produced in such enormous quantities, is of relatively small importance.

It is remarkable that the main by-product of the bisulphite process is still for the most part an absolute waste, notwithstanding the many investigations of technologists and attempts to convert it to industrial use. As it represents a percentage of the wood pulped equal to that of the cellulose obtained, it is a waste of potentially valuable material that must be termed colossal. Moreover, as a waste to be discharged into watercourses, it becomes a source of burden and expense to the manufacturer, and with the increasing restrictions on the pollution of rivers it constitutes in many localities a problem to be solved only by the cessation of the industry. The alternative in such cases is dealing with it destructively—that is, by evaporating and burning it. In this treatment the high calorific value of the organic matter appears on the credit side; but, as calcium and magnesium bisulphites are used, the residue from calcination is practically without value. If, however, a soda base is substituted, the alkali is recoverable in such form as to be directly available for the alkaline-sulphide or Dahl process. As a more complicated alternative the soda can be recovered by the old black-ash or Leblanc process, and the sulphur by the now well-established Chance process, in which lime must be added to the concentrated liquors before calcination. The engineering features of the system in respect to evaporating and calcining are the same. Economic working requires (*a*) evaporation by multiple effect and (*b*) calcining on the continuous rotary principle. For the latter process the draft of air is concurrent, by a special device, with the movement of the charge in the furnace, a feature by which a progressively increasing temperature within the furnace is procured. This interesting development has been elaborated by Drewson and Dorenfeldt, to whose publications readers who wish to inform themselves in detail in regard to these developments are referred. The present necessity of a destructive treatment of the sulphite waste liquor being assumed, their scheme has many advantages; sodium bisulphite liquors are more economically prepared and the pulp obtained is superior in paper-making quality and in economy of bleaching to that resulting from the calcium or magnesium bisulphite processes. The soda may be recovered in a form in which it is immediately available as a powerful hydrolyzing alkali in the manufacture of soda pulp, so that these two systems become complementary to one another. The employment of soda as the base also affords a new motive for developing the electrolytic processes of decomposing salt.

---

[a] German patent No. 99682.

[b] A text-book of paper making, 2d ed., 1900, p. 143.

Cross and Bevan's comments present an excellent summary of conditions at the close of 1900. Significant of more recent developments in the methods of utilizing or disposing of this waste is the fact that in their second volume of "Researches,"[a] a treatise purporting to review all work of importance on cellulose industries during the years 1900–1905, these authors make no mention whatever of the sulphite waste problem.

AMOUNT OF WASTE PER TON OF PULP.

It is now practicable to inquire more carefully into the amount of the waste and its general characteristics. The important facts to be considered in any discussion of stream pollution are the amount and the character of the polluting material independent of the amount of water in which it may be carried. Chemical analyses of the waste liquor in connection with accurate determinations of its volume would furnish the requisite information, and such procedure is usually adopted. In the present case, however, it happens that the amount of polluting material bears a definite relation to the total product of the mill in pulp, independent of slight modifications of the process, whereas the amount of diluting water varies greatly in different mills and even from time to time in the same mill. For example, some mills use the old-fashioned rotary digesters, in which it is not necessary to use more than half the amount of water in the acid liquor that is used in upright digesters. The washing process is often conducted at places where water is plentiful, with a total disregard of economy in water, while in other mills strict economy of water is necessary; therefore the concentration of the waste liquors may be three or four times as great in one case as in another. In view of these facts and of the statement made above, that a definite amount of polluting material is produced for each ton of pulp turned out, it appears that the best procedure is to determine the definite relationship between the amounts of pulp and solid waste. Results obtained at one mill are applicable to any mill using a similar process, though the actual volumes of the wastes may be greatly different. After having determined this fundamental relation, it is of interest to compare the figures obtained with actual analyses of the waste liquor. Such comparison will give an approximate measure of the volume of diluting water.

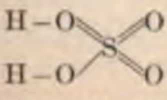
---

[a] Researches on cellulose, 1900–1905.

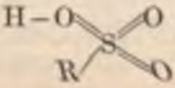
A cord of spruce wood ordinarily handled at the mill will weigh about 3,600 pounds, of which about 55 per cent, or 2,000 pounds, is actual wood substance, the remaining 45 per cent being water. The amounts of chip dust, knots, etc., which are really insignificant as compared with the total weights, may be neglected in this calculation. About 1,100 pounds of so-called "air-dry" pulp having 10 per cent water, or, roughly, 1,000 pounds of actually dry pulp, is made from 1 cord of wood. Therefore the production of 1 ton of pulp is accompanied by the production of an equal amount of waste organic material that is discharged in the waste liquor. According to the analysis on page 10, the sulphite liquor contains 0.7 per cent of calcium and 1.8 per cent of sulphur, equivalent, respectively, to 0.058 pound and 0.150 pound per United States gallon. On the basis of 16,000 gallons of acid liquor to a digester charge, which produces 7 tons of air-dry pulp, each ton of pulp is represented by 132 pounds of calcium and 343 pounds of sulphur. About 0.1 per cent of sulphur dioxide, or 9 pounds of sulphur per ton of pulp, is left unoxidized at the end of the "cook." Of the remaining 336 pounds of sulphur 10 per cent may be allowed for loss of free sulphur dioxide in the relief, leaving approximately 300 pounds of sulphur which has been oxidized in the process. The first product of this oxidation is probably sulphuric acid, according to the following equation, the oxygen being derived from the wood during the digestion:

$$SO_2+O+H_2O=H_2SO_4.$$

This presents the simplest idea of the digestive action. Sulphurous acid is oxidized to sulphuric acid with a corresponding reduction of the wood substance. The fate of the sulphuric acid thus formed has not been satisfactorily determined. It is known that in the final product there is little free sulphuric acid. The first effect of its formation would be the precipitation of calcium sulphate, probably on the wood fibers. As magnesium sulphate is soluble, this is probably the reason why dolomitic lime gives such excellent results. If, however, all the calcium or magnesium originally used were converted to sulphate, there would be needed for that reaction only 100 pounds of sulphur, leaving still 200 pounds of sulphur unaccounted for. It will be shown when the chemical nature of the waste is considered that, according to prevailing views, the sulphuric acid from this amount of sulphur again reacts with a portion of the wood substance to form a so-called sulphonic acid. This may be regarded as sulphuric acid in which one of the OH groups has been replaced by an organic radical (R) thus:



Sulphuric acid.



Sulphonic acid.

reacti is not complete and a small amount of sulphuric acid is generally left in the liquor. For the present it will not be necessary to discuss the relative amounts of these two acids. The waste material resulting from the digestion of sufficient wood to make 1 ton of pulp may be summarized as follows:

Materials in the waste liquor per ton of pulp.

	Pounds.
Wood material	2,000
Calcium sulphate	449
Sulphur dioxide (omitted from total)	18
Sulphur in sulphuric acid and in organic combination	196
Total solid matter	2,645

CHEMICAL COMPOSITION OF THE WASTE LIQUOR.

As has been stated, the actual strength of the waste liquor is entirely a matter of dilution. The 16,000 gallons of acid liquor used in the "cook" producing 7 tons of air-dry pulp is usually diluted with one to two times its volume of water in the blow pit, and other wash waters later mingle with this liquor in the drains. For the purpose of study, however, it is advisable to procure samples of the undiluted waste liquors directly from the digester, because in any plan for the recovery of this liquor it will undoubtedly prove advantageous to separate the undiluted liquor. For the investigation here reported samples of the liquor were collected from the bottom of the digester just before blowing. The hot liquor was drawn into a barrel, allowed to cool, and then bottled in carboys for future use. The subjoined table gives analyses of this liquor and the figures of several analyses of similar liquors by other chemists.

Analyses of sulphite pulp waste liquor.

[Grams per liter.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Total solids	95	82	88	85	93	92	109	52	64
Loss on ignition	82	68	75	69	81		90	45	56
Ash	13	14	13	16	12		19	17	8
Analysis of ash:									
Calcium (Ca)	2.2						6.9	1.76	2.08
Magnesium (Mg)	1.2						.18	.97	1.26
Sulphur (S)	2								
Total sulphur	10.5					9.2			
Free sulphur dioxide (SO_2)	1	2.6	2.2	2.9	2.6	3.8		.94	.90
Sulphite radicle (SO_3)		7.3	7.9	6.7	1.2	3.8	3.8	1.10	1.36
Sulphate radicle (SO_4)		4.1	5.4	4.8	2.7	1.9	7.2	[a]9.27	[a]11.10
Oxygen consumed	36	52	52	50	60				
Specific gravity								1.024	1.028

[a] Exclusive of the organic S.

No. 1, by the writer, is the average of two analyses of waste liquor collected directly from the digester at the Mechanicsville mill. 2 to 6, inclusive, are quoted by Hoffmann,[a] Nos. 2, 3, 4, and by Wickelhaus,[a] and No. 6 by Lehman. No. 7 is given by Schubert,[b] and Nos. 8 and 9 are taken from the notebook of S. C. Lindberg, paper-mill chemist, who has kindly permitted their use.

---

[a] Hoffmann, C., Practisches Handbuch der Papier Fabrikation, Be

These analyses give an excellent idea of the general character of the liquid. The proportions of the various constituents are in agreement with the figures which have been calculated from the amounts of raw materials used. The analyses also determine satisfactorily the nature of the inorganic matter in the waste and show the relatively large amount of organic matter present, about 80 per cent of the total solids.

CHEMICAL NATURE OF THE ORGANIC MATERIAL.

Thus far only the total amount of waste material in the liquor resulting from the digestion of 1 ton of dry pulp and its division into organic and inorganic constituents have been considered. The chemical nature and the essential characteristics of the organic matter deserve further consideration. Though our knowledge of the chemistry of wood is not extensive, the following facts seem to be definitely settled and may be accepted as embodying all that is positively known. The wood substance itself, freed from the relatively small amount of intercellular matter, such as gums and sap constituents, is a homogeneous material of fairly constant composition. To this substance chemists have given the name ligno-cellulose. Ligno-cellulose can be broken down by suitable chemical treatment into two or more substances. These are cellulose, which is the material of the wood pulp, and a complex substance or mixture variously called lignose, lignin, or lignone. It is this latter body or mixture of bodies which in the sulphite process is supposed to be sulphonated, giving rise to a substance known as lignon-sulphonic acid. The constitution of this substance is not known, nor is its chemical identity even assured. Beyond these meager facts all is hypothesis, despite the large amount of experimental work which has been done on the substance under discussion. Probably the best estimate of the character of lignone is given by Cross and Bevan,[c] who made an exhaustive study of the subject.

They conclude that it is a single substance made up of (*a*) $2C_{18}H_{18}O_{10}$, a ketone transitional to quinone which chlorinates directly to marriogallol; (*b*) $6C_5H_4O_2$, furfural, in combination by condensation with (*a*) and (*c*); and (*c*) $5C_2H_4O$, acetic residue. The simplest empirical formula for their lignone is $(C_6H_6O_3)n$, *n* being not less than some multiple of Tollens[a] gives as the result of his analysis of the sulphonated form the empirical formula—

---

[a] Papier Zeitung, 1895, No. 38.

[b] Schubert, Max, Die Cellulose Fabrikation, Berlin, 1892.

[c] Cross, C. F., and Bevan, E. J., Contributions to the chemistry of lignification: Jour. Chem. Soc., vol. 55, trans., 1889, p. 199.

$$C_{24}H_{23}O_7(OCH_3)_2.(SO_3H).$$

This formula must be slightly modified in view of Cross and Bevan's satisfactory determination of the presence of 5 acetic residues in the C_{76} molecule, instead of 6, as given by Tollens's formula. It has been stated that the chemical identity of the sulphonated form has never been satisfactorily shown. The experimental work on sulphite liquor, conducted by the author, seems to prove that the substance in question is probably not a true sulphonic acid.

PURIFICATION OF SULPHITE WASTE LIQUOR.

Investigations on the disposal of waste liquors may be carried out either with the object of recovering and utilizing the material contained therein or with the simpler aim of purifying the liquid so that it may safely be discharged into a stream. The former method of investigation has appealed most strongly to manufacturers and chemists, and a great many attempts have been made to discover some useful by-product in the waste sulphite liquors. Reference to these investigations will be made later. Owing to the failure in general of all such attempts and to the stringent laws against stream pollution, particularly in Germany, some attempts have also been made simply to purify the liquor by precipitating the organic matter, the experiments having no reference to the recovery of valuable by-products. One of the earliest of these investigations was made by H. Frank,[b] who gives the following composition of the sulphite waste which he used:

Composition of sulphite waste.

	Grams per liter.
Total solids	82
Loss on ignition	59
Ash	23
Calcium (Ca)	5.3
Magnesium (Mg)	.25
Sulphate radicle (SO_4)	14.4

In the process developed by Frank the liquor is treated first with lime to neutralize the free acid and then with chimney gases to carbonate the excess of lime and oxidize the calcium sulphite. A heavy precipitate of sulphate and carbonate is formed and it is claimed that much of the organic matter is dragged down, so that the supernatant liquid could be discharged into the stream. This process was later investigated more thoroughly by F. B. Ahrens, E. Klingstein, and P. Schubert,[c] who state that many German wood-pulp have been compelled to close because it was found impossible mply with the requirements of rivers-pollution officials. The nation of the waste sulphite liquor which they used showed t gave a strongly acid reaction, had a specific gravity of 1.0465 8° C., and was optically inactive. The dry residue was 9.4 per of which 1.11 per cent was ash and 8.29 per cent organic matter— rictly accurate determinations. The liquors from the digesters nearly neutralized by passing them over limestone. The hot as then mixed with a known quantity of fresh lime water once , filtered, and the filtrate neutralized with carbonic-acid gas. esults obtained are shown in the following table:

---

[a] Quoted by Cross and Bevan, Researches on cellulose, p. 128.

[b] Wien. Jahresbericht, 1887, p. 1177.

[c] Zeitschr. angew. Chemie, 1895, p. 41.

Results of experiments in neutralizing hot sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2	8.75	1.80	6.95
3	7.48	1.59	5.89
4	7.36	1.71	5.65
5	7.13	1.56	5.57
6	6.86	1.52	5.34
7	6.74	1.58	5.16
8	6.65	1.54	5.11
9	6.61	1.57	5.04
10	6.79	1.51	[a] 5.28
11	6.54	1.55	4.99
12	6.52	1.49	[a] 5.03
15	6.31	1.49	4.82
20	7.00	1.60	[a] 5.40
30	4.99	1.01	3.98

[a] Organic matter rendered soluble again by boiling.

en the liquors were treated cold, the following results were ned:

Results of experiments in neutralizing cold sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2	6.21	1.11	5.10
3	6.19	1.33	4.86
4	5.26	1.00	4.26
6	5.08	1.04	4.04
8	4.96	1.10	3.86
10	5.67	1.22	4.45
12	5.76	1.23	4.53
14	6.26	1.29	4.97

lium aluminate was also tried as a precipitant, but the results ess satisfactory. *The precipitated and neutralized liquors were reated electrically.* A current of 5 amperes and only sufficient potential was passed through the liquid between platinum electrodes, but no diminution in either mineral or organic matter was observed after two hours. A high-tension current (106 volts) was then tried, but the results were equally ineffective after a test of the same duration. It is evident, these authors conclude, that the objectionable organic matter, if removable at all, calls for some process hitherto undiscovered. Ahrens tried, unsuccessfully, to treat this waste bacterially after neutralization on the lines of his patent. It was found absolutely sterile to begin with, and the amount of bacterial filtration required for its decomposition was altogether impracticable. E. Bruch[a] found that if the waste liquors are treated when acid, or neutral, with leather glue, a compound of tannic acid and glue is formed which coagulates on storing and becomes highly viscid. If then the clear, colorless top liquor is decomposed with aluminum sulphate, another gummy precipitate is formed. Both precipitates are soluble in alkalies and in weak ammonia, and may be removed, dried, and powdered. If the clear liquor is then neutralized with chalk or lime, a precipitation and clarification ensue, and the top liquor is free from smell and has lost about 25 to 30 per cent of the total organic constituents, and these the most easily decomposable.

UTILIZATION OF SULPHITE WASTE LIQUOR.

By far the most important work on this waste liquor has had for its object the utilization of the organic matter. Its complex chemical nature and relatively large amount and the fact that it is still a chemical mystery make the field particularly inviting for research. In some interesting laboratory experiments made by Buddens,[b] and quoted by Griffin and Little,[c] the waste liquor was neutralized by ammonia, the lime was precipitated by ammonium carbonate, and the carbonate of lime thus formed was separated by filtration. The dark-brown filtrate was evaporated and the dried residue distilled. The dried residue contained 7.2 per cent of ammonia as salts. Water and a yellow oil were obtained in the condenser, and finally a crystalline sublimate appeared on the walls of the tube. The escaping gases were caught in a gasometer. The oil had at first a mercaptan-like odor, but this disappeared on heating slightly. The odor was without doubt due to organic sulphur compounds, which were present in traces. The mixture of oil and water was, after this heating, distilled with steam, the distillate was shaken out with ether and then dried, and the ether was evaporated over calcium chloride. The brown oil that remained boiled at 130° C., and as it colored a pine chip moistened with hydrochloric acid a strong carmine, it was believed to be pyrrol. Pyrocatechin was also found in the distillate, as was proved by color tests with iron salts and by the reduction of Fehling's solution. The gases from the first distillation were carbon monoxide, hydrogen, marsh gas, and hydrogen sulphide. Four hundred grams of the residue yielded 180 grams of coke, 30 liters of gas, and 200 grams of distillate. Mucic and saccharic acids could not have been present as such in the liquor, because they are formed by the oxidation of carbohydrates, and the action of the liquor is a reducing one. Yet pyrrol is formed by distilling the ammonium salts of these two acids. The only way of accounting for pyrrol is by considering that succinic acid is formed from the resins in the wood—a not improbable assumption. Ammonium succinate changes readily into ammonium succinamide, which gives pyrrol when it is heated with reducing agents. The presence of pyrocatechin is due to the presence of dioxybenzoic acid (1, 3, 4), which is in the liquor as dipyrotechnic acid. The decomposition of this acid by distillation with ammonia produces tannic acid and pyrocatechin. Doctor Buddens states that there is no tannic acid in the liquor, which will give a blue-black color with ferric chloride, because the tannin in wood is reduced by digesting with sulphurous acid. The reduction is probably due to dipyrocatechuic acid, but by treating the liquor with ammonia and distilling, tannic acid is eventually formed. Sulphites are oxidized to sulphates when the tannin is reduced. It is possible, therefore, that the difficulty of pulping wood rich in tannin by the sulphite process is due to the action of the tannin, which renders the sulphurous acid ineffective. Lindsey and Tollens,[a] in their systematic search for the different sugars, used liquor from a Mitscherlich slow-process cook, with a specific gravity of 1.055, showing total solids 9.5 per cent, and calcium 0.41 per cent. The solution was pale yellow in color and strongly reduced Fehling's solution. They found no evidence of the presence of saccharose, dextrose, or dextrose-yielding sugars, traces only of levulose or levulose-yielding sugars, and but a small amount of galactose. On the other hand, mannose, determined as a hydrazine, was found to represent 6 to 7 per cent of the original total solids. Furfural was found in some quantity on heating with hydrochloric acid, and xylose was identified in the solution. Alcoholic fermentation of the liquor gave amounts of alcohol corresponding to only 1.2 per cent of the total carbohydrates. The remaining gummy mass behaved as a homogeneous complex, yielding several synthetic preparations, the analyses of which were consistent with the view of its homogeneity.

---

[a] *Die Abwässerreinigung der Cellulose-Fabriken und die Papierleimung:* Chem. Zeitung, 1892, p. 1782.

[b] *Buddens, W.,* Papier Zeitung, March, 1891.

[c] *Griffin and Little,* Chemistry of paper making, New York, 1894.

---

[a] Liebig's Annalen, No. 267, 1892, p. 341. Abstracts Jour. Chem. Soc., 1892, p. 932.

A summary of various attempts to recover valuable products from the waste has already been given (pp. 15–18). Thus far no satisfactory recovery of valuable chemical substances has been made. The substance itself has been used as a substitute for glue and for sizing. Mitscherlich precipitated the tannin compounds with glue in the presence of alum and sulphuric acid, obtaining a rubbery mass, soluble in weak alkali, which could be used in engine sizing. He later improved the process[a] by precipitating with lime to remove the sulphite present and then diffusing the liquor through membranes. The diffusible portion contained sugars and was fermented for alcohol. The nondiffusible part was treated as described above in order to remove the tannins. A later patent[b] describes a process in which, after the removal of the calcium salts, the liquor is heated with hair or bone to give a semiwaterproof sizing. V. Drewnen and L. I. Dorenfeldt[c] treat the liquor with soda ash recovered from the soda pulp process, precipitating the lime and a part of the organic matter. They draw off the clear liquor and burn the residue, using the heat of the combustion to evaporate more liquor. The liquor is said to contain more calorific energy than is necessary to evaporate it. The soda ash is recovered from the residue by the usual process, and about 60 per cent of the sulphur is recovered by liberating free sulphur dioxide with carbon dioxide gas. The fumes and the gases from the evaporation were found to be very corrosive. This trouble was finally overcome by combining the wastes of the sulphite and soda pulp mills and treating them like soda wastes. Frank's process, as described by Schubert,[d] consists in precipitating the remaining calcium bisulphite as normal sulphite with excess of lime, after which the precipitate is redissolved in an excess of sulphur dioxide. Such treatment would recover only a small part of the total sulphur. Meyer's process, also described by Schubert,[e] seeks to recover valuable products by destructive distillation of the organic material in the waste. The liquors are neutralized, concentrated to a thick sirup, mixed with charcoal to a paste, and distilled. The yield of valuable products is too small to make the process economical. H. Seidel has employed the soda salt of the lignone sulphonic acid as a reducing agent in chrome mordanting wool, where, under the name "lignorosin," it is used in place of tartaric and lactic acids.[f] The material, especially when concentrated, is very sticky, and many attempts have been made to utilize it as a substitute for glue. In J. S. Robeson's process[a] for the manufacture of an adhesive, which is being used at Ausable Forks, N. Y., by a large mill,[b] the waste liquor is neutralized with lime and evaporated in vacuo. The product is a thick, molasses-like fluid, which finds application in foundries as an adhesive in core making. C. H. Voight[c] makes a glue substitute by heating starch and a peroxide with the sulphite liquor. A. G. Brooks[d] evaporates the liquid till it contains 20 per cent water, then adds carbohydrates or albuminoids and dries the mass, which is used for fuel, pitch, glue, resin, or size. Knoesel[e] concentrates to 25° B. and treats with a slag meal high in phosphorus (Thomas slag). It is claimed that the phosphorus of the slag is rendered soluble in citrates and becomes available in fertilizing. Ahrens[f] investigated the process and could not substantiate its claims. Processes have been proposed for the destructive distillation of the substance, and, as has already been stated, both pyrrol and pyrocatechin have been obtained in this manner. The yield of these products has not been sufficient to make the process successful. Patents have been granted for processes involving the use of the liquor in tannin.[g] According to Seidel[h] 28 per cent of the solids are removed by rawhide powder. No satisfactory method has yet been described for separating the tannin substance from the remainder. This seems to be one of the important lines for future investigation. Morterud[i] subjects the hot liquors to a partial vacuum and removes from them a considerable volume of sulphur dioxide. Bergerhopf[j] made a cheap grade of paper for newspapers by using the waste liquors to digest sawdust. Eckman[k] "salts out" the liquors and makes a concentrated solution, which he calls "dextrone," a substitute for dextrin, or British gum.

---

[a] United States patent No. 681241, 1901.

[b] United States patent No. 687844, 1901.

[c] United States patents Nos. 620755, 1899, and 726036, 1902.

[d] Schubert, Max. Die Cellulose Fabrikation, Berlin, 1892.

[e] Op. cit.

[f] *Rev. gén. des mat. col.*, vol. 2, 1898, p. 370. Jour. Soc. Chem. Ind., vol. 17, 1898, p. 1043. British patent No. 19005, 1897. German patent No. 99682, 1897.

EXPERIMENTAL INVESTIGATIONS WITH THE ORGANIC MATERIAL.

The knowledge of the chemical reactions which characterize lignone is very meager. Early in the present study it was deemed important to obtain additional light on the general behavior of this material. It was hoped that in this way knowledge of its chemical nature might be enlarged and particularly that some reactions of industrial value m t b ered. For this study preparations of the dry material were made in various ways; the solubility of these preparations was investigated; attempts were made to identify a sulphonic acid in the naterial; and various other reactions were studied.

---

[a] United States patent No. [illegible]

[b] Paper Trade J. [illegible]

[c] United States patent No. [illegible]

[d] British patent No. [illegible]

[e] Jour. Soc. Chem. Ind. [illegible]

[f] Chem. Zeitung, vol. [illegible] 1905, p. 343.

[g] German patent No. [illegible]

[h] Zeitschr. angew. Chem. [illegible]

[i] United States patent No. [illegible]

[j] German patent No. [illegible]; Jour. Soc. Chem. Ind. [illegible]

[k] German patent No. [illegible]

PREPARATION OF CRUDE "LIGNONE."

Three different preparations of the dry material were used. "Lignone A" was obtained in dry form at the mill. It was observed that ertain steam pipes passing near the blow pit were heavily coated with hard vulcanite-like substance, nearly an inch thick in places. About a pound of this material was chipped off and used in certain of these experiments. "Lignone B" was the supposed calcium compound obtained by evaporating the liquor to one-half volume and salting out with common salt. A granular amorphous substance, containing some salt and moisture, was obtained. "Lignone C" was supposed to be the sodium compound. When the liquor was neutralized with sodium carbonate and allowed to settle, a large amount of calcium carbonate was precipitated. The remaining liquor was evaporated and salted.

SOLUBILITY OF CRUDE "LIGNONE."

The solubility of each of these preparations was tested with several solvents in an endeavor to obtain a liquid from which the material could be crystallized. No solution took place in either hot or cold benzoin, amyl alcohol, allyl alcohol, petroleum ether, amylene, amyl acetate, aniline, toluene, xylene, nitrobenzene, carbon bisulphide, ethyl ether, or benzol. Benzoin seemed to soften the substance. The tests were repeated after acidifying to see if a free acid could be found which would dissolve, but the results were again negative. The two alcohols dissolved the samples if diluted with water. Ordinary ethyl alcohol also dissolved it, a result probably due to the water present. Absolute ethyl alcohol was not tried.

REACTIONS WITH PHOSPHORUS CHLORIDES.

An important general reaction of sulphonic acids is that with phosphorus pentachloride, giving sulphon-chlorides according to the reaction—

$$R.SO_2.OH + PCl_5 = R.SO_2.Cl + POCl_3 + HCl.$$

Sulphon-chlorides are for the most part insoluble oils which combine with ammonia to form crystallizable sulphonamides, as follows:

$$R.SO_2.Cl + 2NH_3 = R.SO_2.NH_2 + NH_4Cl.$$

Appropriate mixtures of the crude "lignones" with varying amounts of the pentachloride, the oxychloride, and mixtures of the t made. No indi ny reaction was obtained at ture or at temperatures up to 180° C., at which point the oxychloride begins to distill. Altogether about twenty attempts were made to bring about this reaction. The products after heating were treated with ammonia, but no evidence of any amide was ever obtained. It must be concluded, therefore, that the "lignone" does not react with the chlorides of phosphorus in the way which characterizes sulphonic acids in general.

FUSION WITH ALKALI.

Another characteristic of sulphonic acids is their ready reduction to corresponding phenols on fusion with caustic alkali according to the reaction—

$$R.SO_2.OH + 2KOH = K_2SO_3 + R.OH + H_2O.$$

Preparations of "lignone" were fused in this way, the resulting masses being extracted with ether and evaporated. Only mere traces of ether extract were obtained, and these gave none of the usual tests for phenols. During the fusion the sulphur gave strong evidence of its escape into the air in the form of some volatile mercaptan, with a very penetrating and sickening odor.

POSITION OF THE SULPHUR IN "LIGNONE."

As in both series of tests just described the "lignone" failed to react in a way characteristic of true sulphonic acids, the presumption is reasonable that a sulphonic acid is not present. An interesting question is therefore raised. How is the sulphur in this material related to the molecule? In the salting-out experiments some light was thrown on this question. It was found that a considerable part at least of the sulphur was in such loose combination that it was given off as sulphur dioxide in the cold during the salting process. The result when first observed was attributed to the sulphur dioxide in the liquor, but it was possible to show that such was not its origin. A small amount of the fresh liquor was cautiously evaporated nearly to dryness and then diluted with water to the original volume. This solution was then salted in parallel with a fresh solution. As nearly as could be determined by the sense of smell, equal amounts of sulphur dioxide were given off by both samples. Confirmatory results were obtained by dissolving some of "lignone A," a completely dried sample, and treating it in the same manner. That all the sulphur could not be removed by this procedure was evident on drying and igniting the salted sample, when the same disgusting odor was given off as by the original sample and apparently to the same degree. This point was verified quantitatively by titration with iodine solution. When the solution was acidified, an evolution of sulphur dioxide occurred and the reducing power increased from an equivalent of 0.01 per cent to 0.104 per cent of sulphur dioxide. On continued boiling without acid the reducing power increased from 0.011 to 0.015 per cent of sulphur dioxide. Boiling with potassium hydrate still further increased it to 0.201 per cent. Lime water had a similar but less marked effect. All these observations point to the probable fact that a sulphurous ether is present. Such ethers yield sulphur dioxide to sulphuric acid and are readily hydrolyzed by an alkali. The results here obtained are, in all respects, what would be expected from sulphurous ether, and the presence of a sulphonic acid has not been verified. Though the presence of the latter compound has not been disproved, the writer is strongly of the opinion that the major part, at least, of the sulphur is present in the form of an acid sulphurous ether of some complex hydrocarbon radicle.

REACTIONS WITH AROMATIC AMINES.

Previous investigators have generally agreed that "lignone" possesses aldehydic properties. A characteristic property of aldehydes is that of forming condensation products with certain bodies; the aldehyde and the other substance—aniline, for example—condense to form a complex molecule. When a solution of "lignone" was mixed with aniline, a bright-red precipitate was formed. An excess of aniline changed this body to a black insoluble gum. The reaction took place equally well with aniline oil or with aniline sulphate. All attempts to purify the product failed. It was insoluble in all solvents except acids, which apparently decomposed it into its original constituents. Reference will later be made to the action of strong nitric acid on the gum. Exactly similar condensations were observed with the following: Ethyl aniline, diethyl aniline, dimethyl aniline, methyl diphenylamine, *m*-chloraniline, *p*-chloraniline, dichloraniline (1–2–4), *m*-nitraniline, *p*-nitraniline, *o*-toluidine, *p*-toluidine, dibrom-*o*-toluidine, *o*-tolidine. Substituted amines which did not give condensations were *o*-nitraniline and dinitraniline (1–3–5). Bright-red products were formed in every case where the amine retained the NH_2 group. With amines in which substitution had taken place in that group brown or black compounds were formed. The reactions of these preparations with fused sodium sulphide is considered under the caption "Sulphur dyes." As in the case of the aniline condensation product, it was not possible to purify these gummy substances. They were decomposed into the original constituents on treatment with strong acids or generally on heating.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITROUS ACID.

On the assumption that the condensation products still retain their characteristic amine group, they were treated with nitrous acid in an ice bath, in the hope of obtaining some new bodies through the diazo reaction. In the case of aniline this reaction is—

$$C_6H_5NH_2.HCl + NO_2H = C_6H_5N:NCl + 2H_2O.$$

When this substance alone is heated it decomposes, yielding phenol, but in the presence of other substances, such as some unaltered aniline, reactions of technical importance can be brought about:

$$C_6H_5N:NCl + H_2O = C_6H_5OH + N_2 + HCl,$$

or

$$C_6H_5N:NCl + NH_2C_6H_5 = C_6H_5N:N.NHC_6H_5 + HCl.$$

The product of the latter reaction is diazo-amidobenzene, a starting point for the preparation of an important group of dyes. Application of the diazo reaction to the condensation products above described did not generally result in apparent change. In some experiments an excess of the amine reacted in a manner quite characteristic of the amine itself without any substituted groups. The general inertness of these bodies under such conditions leads to the conclusion that substitution takes place in the amido group of the condensation products. This is further verified by the fact previously shown, that all primary amines gave bright-red condensation products, while the others gave brown or black substances.

REACTIONS WITH NITRIC ACID.

Concentrated nitric acid was found to have a very vigorous action on the dry "lignone" preparation and on the sulphite liquor itself at high temperatures. The organic matter of the dry "lignone" is completely oxidized, chiefly to oxalic acid, in the presence of a sufficient excess of the acid. Nitrous acid fumes are evolved, and the odor of acetic acid can be distinctly detected. The action of nitric acid on the waste liquor is less violent. When a mixture of one part strong acid and ten parts of liquor is warmed, action begins at once. Nitrous and acetic acids are evolved, as with the dry product, and the color of the solution changes from dark brown to bright, golden orange. This solution, after neutralization of the free nitric acid by an excess of sodium acetate, was found to dye wool and silk a beautiful orange-yellow. This yellow dyestuff, which for convenience may be called lignone yellow, is of peculiar interest as a product to be recovered that may be valuable, and it was therefore carefully studied.

LIGNONE YELLOW.

Difficulty was at first experienced in separating the dye from the liquid. Cloth could be dyed directly in the liquid with excellent results, but on evaporation the dye lost a great deal of its coloring power. By evaporating it in partial vacuum to a thick sirup and then reducing it to dryness in a warmed vacuum desiccator, it was finally possible to obtain the desired material in dry form. It is a light-yellow powder, very porous, and extremely hygroscopic, which latter property considerably diminishes its commercial value.

Samples of woolen cloth dyed in baths prepared from the dried material in the proportion of 2 per cent of the dye, by weight, were very beautifully colored. The color is retained on boiling for half an hour in soap solution, dilute acetic acid, or dilute alkali. It withstands the action of bleaching powder, chromate, and other oxidizing agents. It will stand direct summer sunlight for two days without apparent discoloration, but it is affected on the third day; so it is, therefore, only moderately fast to sunlight.

Lignone yellow is exceedingly soluble in water and in ethyl alcohol. On evaporation of these solutions it yields a pasty mass which is completely dried with difficulty. When dried at 100° C., it is decomposed with evolution of nitrous oxide. It can be eventually oxidized with nitric acid to oxalic acid. From the manner of its formation it might be thought to be a nitro-body and in its dyeing properties it resembles picric acid; but it differs from the latter and from other nitrophenols in several particulars. Picric acid, or tri-nitrophenol, crystallizes from hot water and is difficultly soluble in cold water. The same is true of para-nitrophenol. Ortho- and meta-nitrophenols melt at 45° C. and 96° C., respectively. The three dinitrophenols are converted to picric acid on further nitration. If lignone yellow is an aromatic nitro-body, it must be more complex than any of the nitrophenols. Repeated attempts to reduce this dye were made, but no amido-body could be detected after attempted reduction with zinc dust, zinc and hydrochloric acid, iron and sulphuric acid, ammonium sulphide, hydrogen sulphide, or the electric current. In no case did nitrous acid bring about any reaction after these attempts at reduction. Generally, the yellow color was not destroyed. Neither weak chromic acid nor bleaching powder destroy the color. Long-continued boiling of the original sulphite liquor with sodium nitrite gives a liquor with feeble dyeing properties, the color being like that of the nitrated substance. It is possible, therefore, that the dye is a nitroso-compound of some complex radicle rather than a nitro-body. All attempts to prove this point resulted negatively and the question of the fundamental character of the dye remains open.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITRIC ACID.

It was thought that the nitration of the substances produced by the condensation of the "lignone" substance with various amines might give rise to dyes of different character, and that the latter might have technical value as well as furnish some clue to the nature of lignone yellow. Accordingly, the different condensations described under "Reactions with aromatic amines" (p. 30) were submitted to the action of dilute nitric acid and the dyeing properties of the resulting solutions were tested on samples of wool. To obtain comparative results, the same quantities of the various components were used each time. As many of the amines are themselves capable of easy nitration under suitable conditions, a blank test was made each time, the amine tested being used without any sulphite liquor. The results of such blank tests as gave a dye in any way similar to that resulting from the condensation product are not recorded as positive. In each test approximately one part of the amine and one part of nitric acid were used with twenty parts of the sulphite liquor. The results of the tests are summarized in the following table:

Nitration of products resulting from the condensation of "lignone" and amines; wool dyed in resulting liquors.

Amine.	Color of dye produced.	Intensity of color.	Color of blank.
Aniline	Golden yellow	Strong	Colorless.
Dimethyl aniline	Dark yellow	Strong	Yellow.
Ethyl aniline	Olive green	Strong	Olive brown.
Diethyl aniline	Greenish yellow	Weak	Colorless.
Methyl diphenylamine	Lemon yellow	Weak	Brown.
m-Chloraniline	Red, washing out yellow	Weak	Pale pink.
p-Chloraniline	Reddish orange	Strong	Colorless.
Dichloraniline	Reddish brown	Strong	Pale orange.
o-Nitraniline	Golden orange	Strong	Colorless.
m-Nitraniline	Golden orange	Strong	Colorless.
p-Nitraniline	Dark orange	Strong	Colorless.
Dinitraniline	Canary yellow	Weak	Colorless.
o-Toluidine	Golden yellow	Strong	Colorless.
p-Toluidine	Dark orange	Strong	Colorless.
Dibrom-o-toluidine	Golden orange	Strong	Colorless.
o-Tolidine	Brownish yellow	Strong	Purple.

With the exception of one or two doubtful cases, it appears that the condensation products enter into reaction with nitric acid just as "lignone" alone does, and that the shade and intensity of the dyes produced by the reaction vary from green through orange and yellow to brown, depending on the nature of the amine that is used. Some general observations can also be made from this study. Substitution in the amido group of ethyl aniline, etc., gives greenish shades, and the lighter the substituting groups the more pronounced the green. In mono-substituted aniline, the para-compounds give the most brilli t and ful dyes, and then in decreasing brilliancy the meta- and the ortho-compounds. The most powerful and brilliant dyes of the series in the table were those produced by *p*-chloraniline, *p*-nitraniline, and *p*-toluidine. Chlor-compounds give the most brilliant dyes; the nitro-compounds give dyes of more strength and body. As with the nitrated "lignone" alone, here also every attempt failed to produce amines from their nitrated substances. Many of the products, it is true, gave a reaction with nitrous acid after reduction, but in all such cases the reaction was that of the amine originally used and the resulting substances could be prepared equally well without the addition of "lignone." Reduction of the nitraniline products was not attempted, as too great complication would arise from the presence of the nitro-groups known to be prese t.

SULPHUR DYES.

Many organic substances yield dyes when fused with a mixture of sulphur and sodium sulphide. These so-called sulphur dyes are now manufactured in a variety of colors. They are direct cotton dyes—that is, they dye cotton without the aid of a mordant—and they are very fast. Their cheapness and valuable properties have caused them to come into wide use. An attempt was made to prepare dyes of this kind from sulphite waste liquor and from several of its condensation products. In particular, it was hoped to obtain dyes of bright color, red or blue, because such colors are especially desirable and bring good prices on the market. Brown and black are much more readily made, and are consequently cheaper. Mixtures of one part dry crude "lignone" and one-half part each of sodium sulphide and sulphur were fused for fifteen minutes at a low heat. The resulting mass was extracted in hot water and the extract filtered and evaporated. From 25 grams of dry "lignone" there were made 20 grams of a green powder, soluble in water containing a little sodium sulphide. This powder was found to be a true sulphur dye, coloring cotton a dark green, which changed to a good black on oxidation in the air or on subsequent treatment in a chrome bath. Compared with commercial dyes in the market, this dye is worth about 7 cents a pound in its impure condition. About half its weight is inert material, which can be removed by proper treatment. Similar experiments in preparing sulphur dyes were made with the condensation products previously mentioned. (See p. 33.) The shades of the resulting dyes were somewhat modified by the presence of the amine but they were all browns, grays, or black. No advantage was apparent in the use of the condensed products over that of the untrea "lignone."

COMMERCIAL POSSIBILITIES OF LIGNONE DYES.

Two of the best dyes, namely, those resulting from the nitration of "lignone" alone and of "lignone" condensed with *p*-chloraniline, were prepared in large quantity, in order to determine the yield and the cost of the process. One hundred grams of dry crude "lignone" were treated with 50 cubic centimeters of concentrated nitric acid (specific gravity 1.42), and the resulting solution evaporated in vacuo. Seventy grams of lignone yellow were obtained. Compared with mandarin yellow, the technical dye approaching it most nearly in color and fastness, it is worth 18 cents a pound. The cost of nitric acid would be 5 cents a pound of dye. To neglect for the moment the cost of evaporating the original liquor, the margin between the cost of the acid and the value of the dye appears to be sufficient to pay for the work of handling. This would be true at places where expediency makes it necessary to evaporate the liquor in any case, and also at places where the dye could be used in liquid form as made. The cost of evaporating the liquor, however, would undoubtedly be greater than the value of the dye. It must also be borne in mind that there is necessarily a limited market for a dye of this kind—a market too limited, in fact, to permit any general adoption of this plan of utilization, even if it were very much cheaper. A similar test of the cost, yield, and value of the dye from *p*-chloraniline gave an additional cost of 9 cents a pound of dye for aniline, making the total cost for material 14 cents a pound. While the color was much more brilliant, its red shade lowers slightly its market value, pure yellows and greenish yellows being in much greater demand for use than browns. As an additional market outlet, however, this dye may possibly help in the utilization of sulphite waste liquor. The actual results attained in this investigation are not considered so important as the fact that a new and interesting series of reactions of "lignone" have been discovered. Further development of these dyes is the work of the skilled expert in textile coloring. It is not too much to expect that such an expert, possessing full knowledge of the technique of dyeing, will be able not only to simplify and to reduce to a practical working basis the methods herein outlined, but also to discover new and more valuable products by further experimentation along similar lines.

CONCLUSION.

The foregoing study of sulphite pulp waste liquor and of the possible utilization of the organic material in it may be summarized in a few sentences.

Stream pollution by the waste from sulphite pulp mills is extensive and wasteful; *every year* over two and a half billion pounds of solid matter from this source are turned into the rivers and lakes of the United States.

The problem of utilizing this immense amount of waste matter has been studied for a long time, and numerous processes for using or for destroying it have been devised, but they are all unsuccessful, either because there is only a limited market for the proposed product or because the suggested process is prohibitively costly.

Successful disposal of the sulphite waste liquor lies obviously in the utilization of the so-called "lignone" in it, but aside from the employment of this substance to a slight extent as an adhesive and as a source of tannin, no practicable way for its direct use has been devised.

The waste consists principally of wood material separated from the wood fiber by the action of a strong sulphite solution on wood chips; it is a compound of "lignone" with sulphur; but the exact nature of the union has not been definitely demonstrated.

Experimental evidence indicates that the sulphur-bearing compound in the waste liquor is not a true sulphonic acid; at all events, it does not react like an ordinary sulphonic acid. Its condensation with the aromatic amines point to its probable aldehydic nature.

Nitration of "lignone" and of its amine condensation products gives a series of dyes the shade and intensity of which vary from green through orange and yellow to brown, depending on the nature of the amine that is used. These substances dye wool directly, giving brilliant colors that are fast to soap, acids, and alkalies, and reasonably fast to sunlight. One of them, named lignone yellow, and made by nitrating crude "lignone" itself, dyes wool and silk a beautiful orange yellow. Fusion of "lignone" with sodium sulphide and crude sulphur produces a sulphur dye that colors cotton dark green, changing to black on treatment in a chrome bath.

A search for new compounds, such as that made in the present investigation, possesses the serious drawback that much time and effort may be spent without tangible results; on the other hand, an important discovery may be made at any time. Certain reactions brought to light in this work with "lignone" reveal great possibilities. Though the dye called lignone yellow has only slight commercial possibilities and is at best but a partial solution of the major problem, yet the opportunities for further progress along this line are pregnant with the ever-present chance of discovering valuable substances. The number of "lignone" condensation products is almost unlimited, and a wide field for investigation is thereby offered. Only a small portion of a large and interesting territory has been covered by these experiments and the results are by no means conclusive. But it is hoped and expected that the mere reopening of this old and practically abandoned problem by calling attention to these new lines of attack may result in renewed investigation and in the ultimate utilization of a substance that to-day is probably the most valuable waste material known to industrial chemistry.

SURVEY PUBLICATIONS ON STREAM POLLUTION.

The following water-supply papers of the Survey discuss stream pollution. Nos. 103, 152, 185, and 194 can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices stated. Any of the others will be sent free, while the edition lasts, on application to the Director of the United States Geological Survey.

72 Sewage pollution in the metropolitan area near New York City and its effect on inland water resources, by M. O. Leighton. 1902. 75 pp., 8 pls.

79 Normal and polluted water in northeastern United States, by M. O. Leighton. 1903. 192 pp.

103 A review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp. 10c. (See No. 152.)

108 Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.

113 The disposal of strawboard and oil-well wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.

121 Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.

144 The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.

152 A review of the laws forbidding pollution of inland waters in the United States (second edition), by E. B. Goodell. 1905. 149 pp. 10c.

179 Prevention of stream pollution by distillery refuse, by Herman Stabler. 1906. 34 pp., 1 pl.

185 Investigations on the purification of Boston sewage, by C.-E. A. Winslow and E. B. Phelps. 1906. 163 pp. 25c.

186 Stream pollution by acid-iron wastes, a report based on investigations made at Shelby, Ohio, by Herman Stabler. 1906. 36 pp., 1 pl.

189 The prevention of stream pollution by strawboard waste, by Earle B. Phelps. 1906. 29 pp., 2 pls.

192 The Potomac River basin—geographic history; rainfall and stream flow; pollution, typhoid fever, and character of water; relation of soils and forest cover to quality and quantity of surface water; effect of industrial wastes on fishes; by Bailey Willis, R. H. Bolster, H. N. Parker, W. W. Ashe, and M. C. Marsh. 1907. 364 pp., 10 pls.

193 The quality of surface waters in Minnesota, by R. B. Dole and F. F. Wesbrook. 1907. 171 pp., 7 pls.

194 Pollution of Illinois and Mississippi rivers by Chicago sewage; a digest of testimony in the case of the State of Missouri v. the State of Illinois and the Sanitary District of Chicago, by M. O. Leighton. 1907. 369 pp., 2 pls. 40c.

37

CORROSION OF WATER PIPES

By **EARLE B. PHELPS**

Report made to the Sanitary Committee of the National Association of the Master Plumbers of the United States, and reprinted from the Report of the Sanitary Committee for 1907-1908-1909

Mr. David Craig,
National Ass'n. Master Plumbers,
Boston, Mass.

Sir:

I beg to submit the following report upon my investigation into the question of the corrosion of water pipes in certain cities of the Middle West. The investigation was undertaken at your request, the following specific questions being presented:

(1). What is the cause of the corrosion noted? In particular does it result from the chemical treatment of the waters?

(2). What is the sanitary significance of the deposits observed in the pipes?

(3). What remedies can be adopted?

The difficulties were stated to be of common occurrence in cities where chemicals are used in treating the water and most especially marked in St. Louis, Mo. Samples of various kinds of pipe which had been in service at St. Louis for various lengths of time were forwarded me, together with an account of the method of water purification in use there and analyses of the water before and after treatment.

The three questions raised will be discussed in the order in which they are given with special reference to the problem at St. Louis.

The Nature and Cause of the Corrosion.

The specimens of pipe submitted were carefully examined with the following results: The action in question is chiefly noticeable in galvanized iron pipes. Specimens of such pipe which had been in service for but a few years were almost completely choked with a yellowish white substance closely adherent to the surface. It was removed only with difficulty and then brought away with it flakes of the zinc coating of the pipe. The latter was evidently much corroded as indicated by the way it flaked off. Specimens of black iron boiler tubing in service for many years showed much less of the deposit and in fact no more than would have been expected when the character of the water is taken into consideration. This deposit was the characteristic hard scale usually formed in boiler tubes when hard waters are in use. Specimens of brass pipe showed no deposit whatever, being apparently as good as new. These facts lead to the belief that the material is not a mere deposition which might occur normally when hard waters are used, but that it resulted directly from the action of the water upon the zinc coating of the pipe. Analysis of the material confirmed this view. It was found to contain over 80 per cent, of pure zinc oxide, with a small amount of carbonate, some silica and a very little carbonate of calcium. The analysis follows:

ANALYSIS OF MATERIAL FROM GALVANIZED IRON PIPE

Oxide of Zinc - -	**80.4%**
Oxide of Calcium - -	**2.1**
Oxide of Iron and Aluminum	**4.0**
Carbonic Acid as Carbonate	**3.2**
Silica and Insoluble matter	**9.8**
	99.5

Such a result can have but one interpretation. The water has a very corrosive action upon zinc, first dissolving it slightly, at the same time oxidizing and precipitating it as an hydrated oxide. Some slight combination with the carbonate of the water then takes place by which an insoluble basic carbonate is formed; at the same time some of the minor constituents of the water are deposited, particularly oxide of iron and aluminum which assist in cementing together the slowly forming zinc compound into a hard concretion.

It is therefore of special importance to determine if possible what constituents of the water are especially responsible for this solvent action. Added interest is given to this point by the assertion that no such results were noticed before the introduction of the present method of treatment. This statement ought not of course to go unchallenged in such an inquiry as this and the writer has been at considerable pains to verify it. The fact is disclosed that in many other places similar difficulties have followed the introduction of water purification systems using coagulants. It is well known, of course, that alum would exert such a corrosive action but in the present case sulphate of iron, and not alum, is used as the coagulant and in general, in any properly operated plant, undecomposed alum never finds its way to the water main. Such a result could only result from mismanagement of the plant and ignorance of the process. The same remarks apply equally to iron sulphate with the additional well-known fact that the iron compound would not in any case directly give rise to the action noted.

Careful study of the analyses submitted throws no light upon the question. These figures are included here as a matter of record. The chemical treatment involves the addition of iron sulphate, commonly called copperas or green vitriol and of lime. The slight excess of lime serves to precipitate the iron which separates out in small flocs. This floculent precipitate settles rapidly, carrying with it most of the suspended clay and the bacteria and much of the color. The lime further acts upon the bicarbonate of calcium and the magnesium salts already in the water, removing them in part. The chemical reaction between the copperas and the carbonates of the water results in an interchange of acid radicals, the carbonate radical being precipitated with the iron and the sulphate radical of the copperas remaining in solution with the calcium. The end result from the chemical standpoint therefore is the removal of part of the calcium and magnesium and of the carbonate radical and the addition of some sulphate radical. The changes brought about by the purification will be clear from the following analyses of the water before and after treatment and the amount of each constituent removed or added:

ANALYSIS OF THE MISSISSIPPI RIVER WATER BEFORE AND AFTER PURIFICATION

(Parts per million)

	Before	After	Removed
Calcium	34.2	19.1	15.1
Magnesium	11.6	5.6	6.0
Sodium	19.7	19.7	0.0
Carbonate radical	153.6	52.5	101.1
Sulphate radical	38.5	59.6	21.1 (addl)
Chlorine	8.0	8.0	0.0
Total	265.6	164.5	101.1

The fact that the zinc alone was attacked suggests the possibility of electrolytic action. The principles underlying these phenomena may be thus stated. If into a dilute salt solution a strip of zinc and one of copper or brass be dipped, and an electric connection be made between their outer ends, a current will flow whose intensity is dependent upon the electrolytic character of the solution. Such a current flows always from the zinc through the water to the copper and its passage constantly dissolves the zinc. Now in any household water pipe system with brass faucets and particularly brass hot water pipes we have just such an arrangement, an electric battery if you will, in which only the zinc pipes are affected and which effect is determined entirely by the character of the water. We have but little exact knowledge of the amount of action to be obtained from any given combination of dissolved substances, too little in fact to enable us to determine in advance just what the action would be in any given case. A simple experiment, however, furnishes the necessary proof that the treated water of St. Louis under these conditions is much more corrosive than the utnreated. For this purpose waters were carefully prepared to duplicate exactly the analyses already given. With each of these waters a small battery was made up as follows: Two glass test tubes were filled with the same water. Into one was placed a strip of zinc and into the other, one of brass. The ends of these strips were connected and the circuit was completed by a piece of platinum wire running from one tube to the other. The two little batteries were then kept under constant observation. Within three days the zinc in the treated water battery was being noticably attacked and the water was rendered turbid by the basic zinc carbonate which was formed. No action was visible on the zinc exposed to the untreated water during the entire time of observation, over two weeks. Of course this experiment was arranged to obtain the maximum effect in a short time. In practice the circuits are not so short and the current is not so strong. The experiment demonstrated conclusively, however, that the altered electrolytic character of the water is the cause of its increased corrosive action.

One other point is worthy of attention here. It is well known that what are called colloidal substances, of which the ordinary coloring matter of water is an example, have the power to neutralize certain electrolytic properties of dissolved salts. In such cases the colloid is generally precipitated. The experiment cited above was repeated after a little coloring matter obtained by steeping some dead leaves had been added to the water. The zinc plate then became slightly tarnished by a dark deposit and was thenceforth protected from the electrolytic action so that its solution was very much, though not entirely, prevented.

Evidently therefore the removal of the coloring matter from the water has also contributed to the undesirable result. To sum up then, this water acts upon galvanized pipes electrolytically, in those places where galvanized and brass pipes are placed in the same system. This action is more severe in the case of the purified water than it would be with the raw river water, owing both to a change in the mineral character of the water and to the removal of the protective effect of the colloidal coloring matter.

Sanitary Significance.

From a sanitary standpoint the action described may be considered quite harmless. The compound of zinc formed is quite hard and not readily removed. In any case only minute traces of zinc are actually oxidized in any short time and the salts of zinc are not among the poisonous metal salts like copper and lead. Oxide of zinc is used in healing ointments for application to raw burns and for treatment of skin diseases. In my opinion no possible danger to the public health exists in this case. The sanitary danger lies all on the side of the untreated water.

Remedies.

Two courses of action suggest themselves as possible remedies. Obviously galvanized pipes are not suited for use with this water in connection with brass faucets and other brass fittings. Either all brass work must be removed, a very serious matter, or some substitute for the galvanized pipe must be found. There would seem to be no alteration possible in the method of treatment at the purification works which would do away with the difficulty. Judging from the chemical analyses it would not appear that this water would have any solvent action upon lead, certainly not upon lead which had been in service a short time. This statement is strictly local, and not of general,, application. For the case in question I suggest a substitution of lead for galvanized iron pipe; as an additional safeguard the solvent action of the water upon lead pipe should be carefully determined by a competent chemist.

In conclusion the results of this study may be summed up as follows:

The waters of the Mississippi River after purification at the water works of St. Louis, are exceedingly corrosive for galvanized iron pipe. This corrosive action has been more noticeable since the introduction of the present system of purification by means of iron sulphate and lime. Similar treatments of waters elsewhere, where either sulphate of iron or sulphate of alumina, (alum), are used, have in many cases resulted in increasing the corrosive action of those waters.

The only essential change in the chemical character of the water in question due to treatment, is the removal of a large portion of the carbonate ions and the substitution of sulphate ions in their place. Chemically considered, the water is not rendered more corrosive for zinc by this change.

In the presence of electrolytic action, however, sulphate ions tend to attack and dissolve the zinc, while carbonate ions protect it.

Very weak electrolytic action is always present when dissimilar metals are in contact with each other and both in contact with a solution containing such salts as are found in this water. Such action is particularly noticeable when the metals are zinc and copper or zinc and brass. Where copper or brass fittings or hot water pipes are employed in the neighborhood of galvanized iron pipes the water in question is bound to set up electrolytic action with the consequent corrosion of the zinc.

No sanitary question is here involved.

The remedy in the particular case of St. Louis lies in the substitution of lead pipe for the galvanized iron pipe now employed. Tin lined or other protected pipes may serve equally well. The water will not have any serious solvent action upon the lead if the specimen analyses submitted are representative. Before making any radical changes, however, this point should be more carefully studied.

As regards other waters of this kind no general statements can be made. Where increased solvent action has followed the introduction of chemical purification processes the cause is probably the same as that assigned in this case. In some cases, however, the substitution of lead pipe might give rise to more serious evils, and the proper remedy can only be determined after a careful study of each individual case.

Respectfully submitted,
EARLE B. PHELPS,
Sanitary Expert.

Boston, Mass., May 25, 1908.

TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Vol. XXI SEPTEMBER, 1908 No. 3

Contribution from the
Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

AN INVESTIGATION OF THE SANITARY CONDITION OF THE GOWANUS CANAL, BROOKLYN, NEW YORK

By CHARLES F. BREITZKE

Introduction

The following is an abstract of a part of the thesis submitted in May, 1906, by Norman P. Gerhard and the writer, at that time candidates for the Degree of Bachelor of Science at the Massachusetts Institute of Technology.

The object in view in the preparation of the original thesis on file in the Engineering Library at the Institute was to investigate the condition of the Gowanus Canal, Brooklyn, New York, and to suggest a plan for remedying the nuisance. The sanitary investigation was made by the writer. The discussion of the methods which might be applied to remedy the conditions was written by N. P. Gerhard. In view of the fact that the problem has also been considered by the Brooklyn engineers and that a flushing tunnel is now under construction, it was thought best in the publication of this abstract to omit N. P. Gerhard's part of this study.

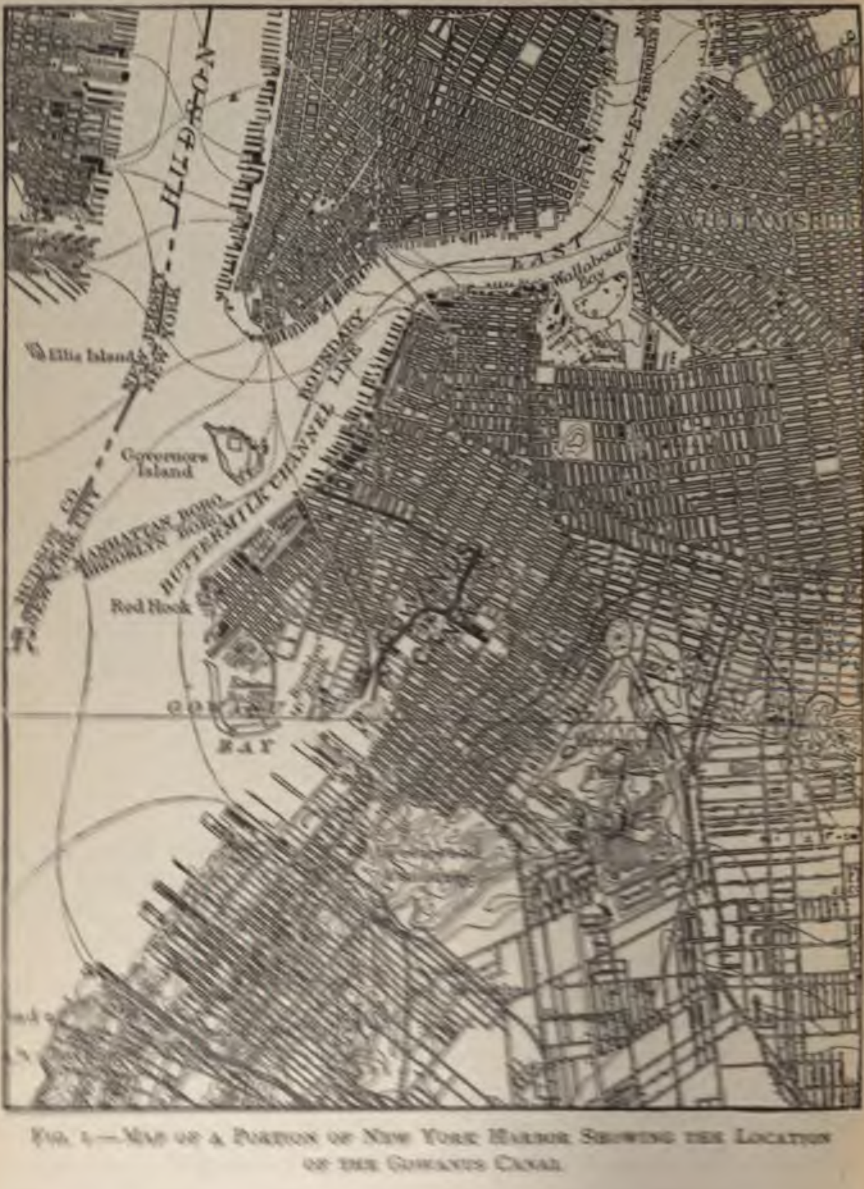


FIG. 1.—MAP OF A PORTION OF NEW YORK HARBOR SHOWING THE LOCATION OF THE GOWANUS CANAL

GENERAL DESCRIPTION

Location. —The Gowanus Canal is located in the western part of the Borough of Brooklyn, City of New York, midway between Prospect

Park and Upper New York Bay. The canal is closed at its upper end and opens at the lower end into Gowanus Bay, a part of New York Harbor. Its position is best seen by a study of the appended United States Geological Survey map (Fig. 1).

Construction and Data. — Originally this portion of Brooklyn contained a stream known as Gowanus Creek. Its shores were everywhere surrounded by great salt marshes formed by the combined action of the tide and the wash from the surrounding upland. This inlet was then navigable at all stages of the tide. Since that time the marshes have been entirely filled in, mainly from gravel knolls which were cut down in the western part of the city. The original shore line in 1776 and the present outline of the canal are shown on the accompanying map (Fig. 2). A glance at the topographical map shows that the land slopes down towards the canal on the north, east, and west; while on the south it is flat, this being made land. For the length of a block on either side of the canal the ground is practically level.

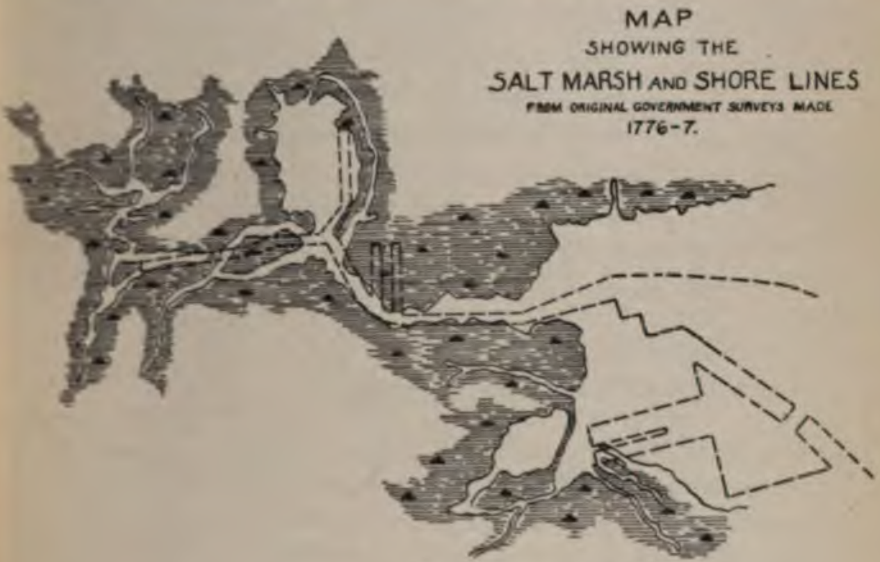
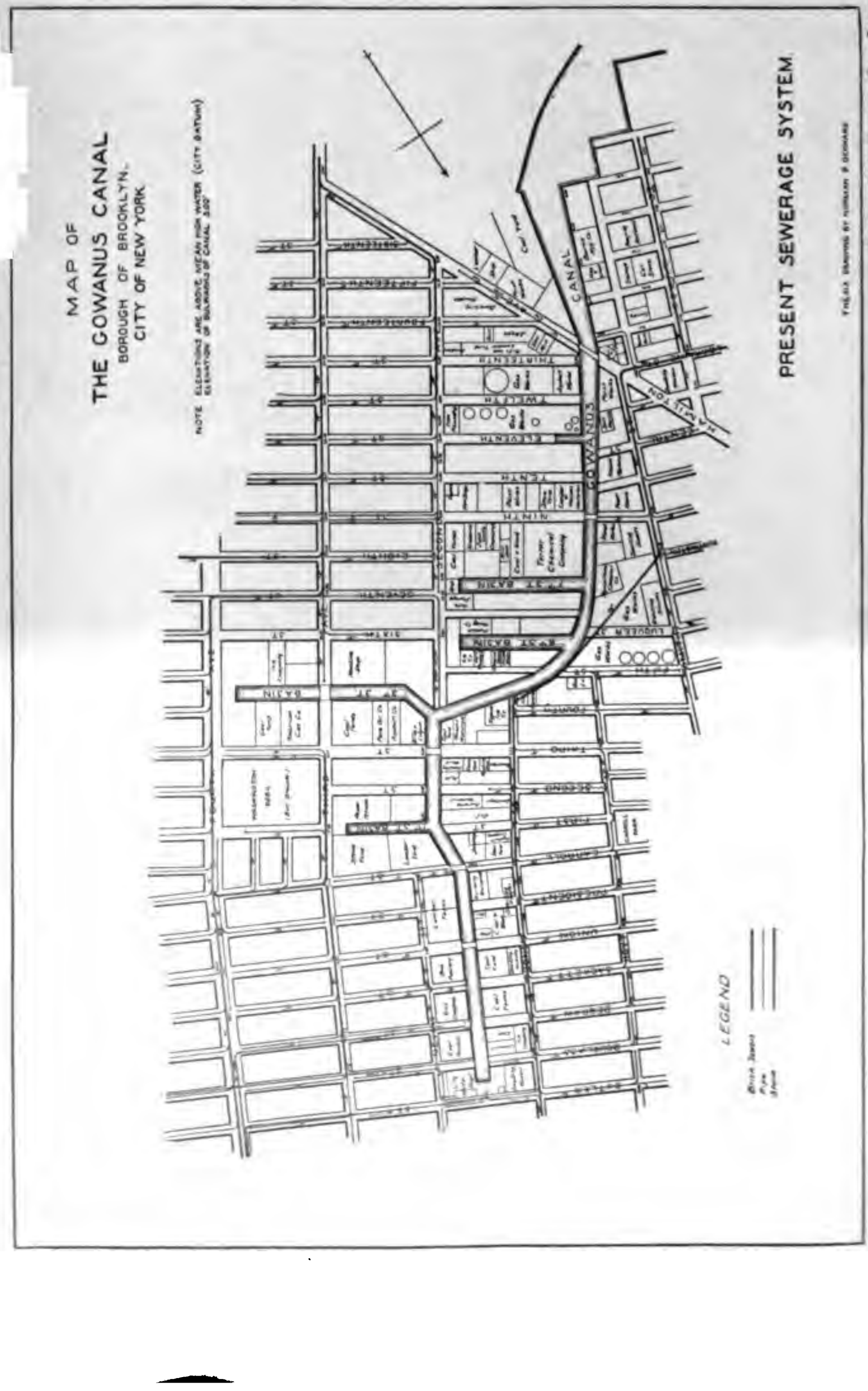

MAP
SHOWING THE
SALT MARSH AND SHORE LINES
FROM ORIGINAL GOVERNMENT SURVEYS MADE
1776-7.

FIG. 2.

The act authorizing the construction of the canal was passed in 1849. The original cost of construction was $452,131, and this was assessed on the portion of the city benefited. The lateral basins provided for were to be built by private enterprise. The date of completion was about 1860.



Scale: 1300 Feet = One Inch

Fig. 3

The canal (Fig. 3) was constructed with two objects in view. One was to drain this section of the city, including an area of about 1,700 acres, chiefly marshes, and to make it fit for agricultural use and building purposes. The other object was to make a navigable waterway for all river and coasting craft, such as sloops and schooners of light draft, towboats, and barges.

The length of the main canal is about 6,575 feet, and the lateral basins are approximately 3,600 feet in length. The total length is, therefore, about 10,175 feet, or somewhat less than two miles. The legal width of the canal is 100 feet. Its average depth is 10 feet below mean low water, but the variations in depth are considerable. At the head it is about 5 feet deep and it grows gradually deeper as Hamilton Avenue is approached. The total capacity of the canal at mean low water is approximately 10,000,000 cubic feet.

Nature of the Locality.—The locality is chiefly a commercial one and consists largely of factories and yards. Certain portions toward the lower end and on the eastern side are not yet built up, and there remain numerous empty lots. The factories and yards extend the entire length of the canal and for the distance of a block on either side. These include gas works, factories, chemical works, ice plants, salt works, oil refineries, asphalt and paving material plants, building material yards, coal and wood yards, power houses, machine shops and foundries, storage warehouses, junk yards, and city dumps.

Immediately adjoining this business section on either side of the canal is a thickly populated tenement district. Gradually, as the distance from the canal increases, more and more houses are found, and the better residence sections are within five blocks on either side.

The photographs accompanying this article (Figs. 4 to 7) give a general idea of the nature of the locality.

Value of the Property.—The assessed value of the land fronting the canal is $3,315,000. The canal enables the abutters easily to obtain supplies of coal, brick, lumber, oil, etc., from schooners and canal boats towed up the canal by tugs. An examination of records on the amount of traffic on the Gowanus Canal showed that during a recent year 26,680 vessels passed Hamilton Avenue, an average of eighty-seven per day. At Ninth Street, Third Street, and Union Street, the average per day was eighty, forty-eight, and twenty-four vessels, respectively. There is no railroad in this part of the city, and the canal is therefore a great convenience.

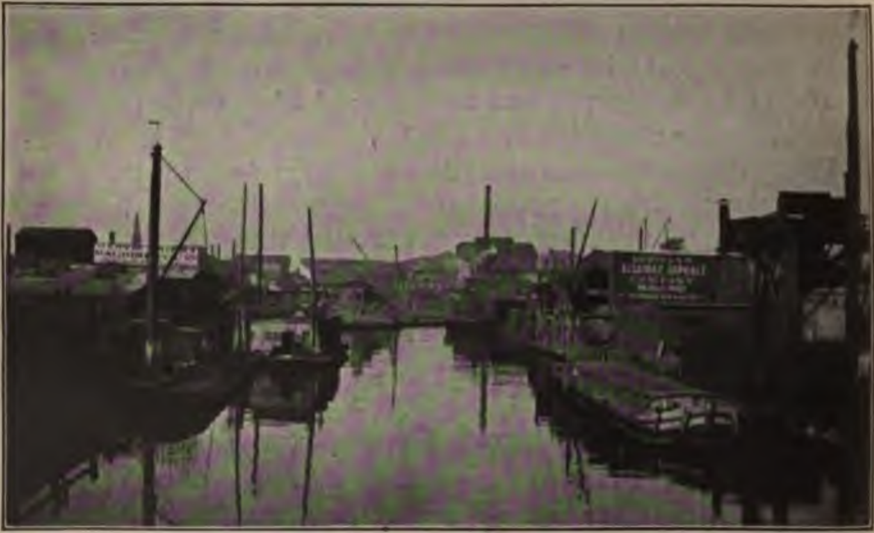


FIG. 4.—FIFTH STREET LATERAL BASIN

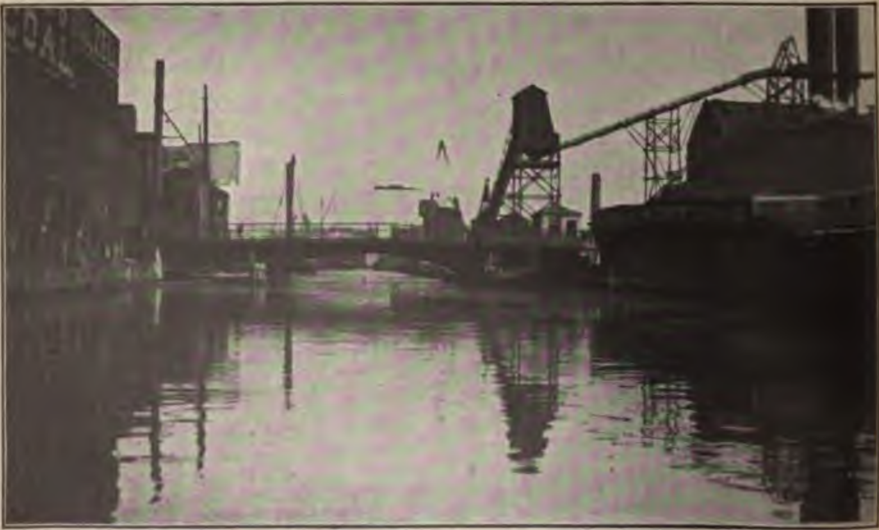


FIG. 5.—CARROLL STREET BRIDGE

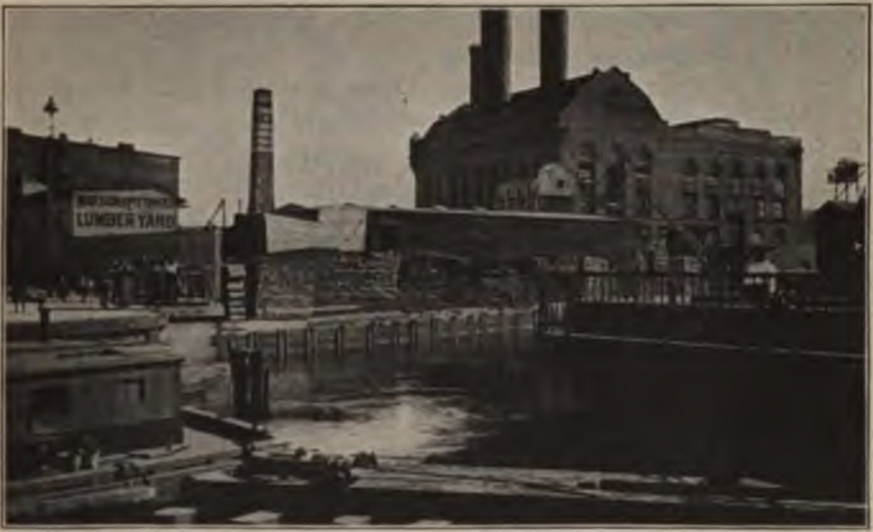


Fig. 6.—View Looking South from Union Street Bridge

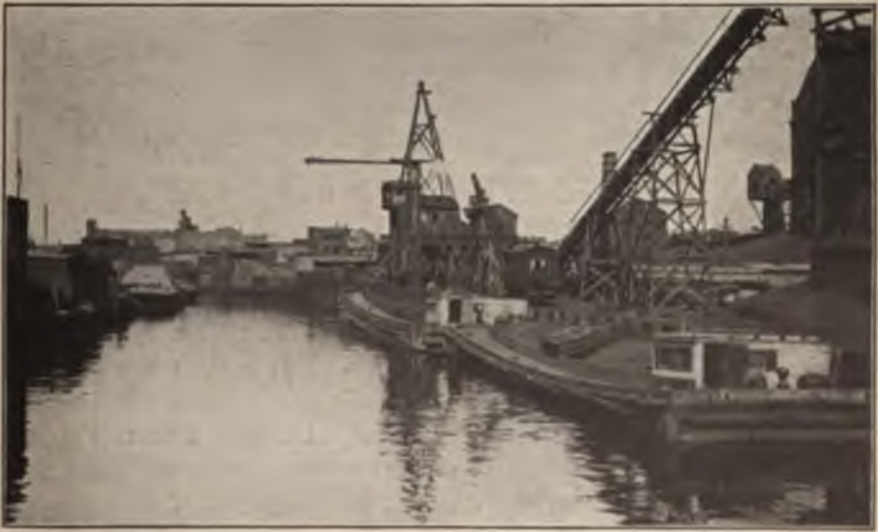


Fig. 7.—view Looking North from Carroll Street Bridge

Tributary Sewers.—With the single exception of Chicago, Brooklyn was the first city in this country to undertake a complete system of sewerage. Therefore when the sewerage system was planned the designing engineer was dependent upon English experience for data in regard to the amount of sewage to be provided for, as well as for the amount of rainfall from any given storm which reaches a sewer within a given time.

The sizes of sewers were determined mainly by the extremes of rainfall, the household sewage being a very small item in comparison. The sewerage was installed in the early sixties. Brooklyn grew very rapidly. Consequently by 1888 the sewers became too small, and the legislature of that year passed an act permitting the discharge of storm water sewers into the Gowanus Canal. In 1892 a 15-foot main relief sewer, which intercepts all the storm water in the mains draining that portion of Brooklyn lying south of Greene Avenue, was brought down to the head of the Gowanus Canal, at Butler Street (Fig. 8), and completed. Nothing but storm water was intended to enter this relief sewer, but, whether by accident or design, it is now flowing during dry weather and is discharging sewage into the canal.

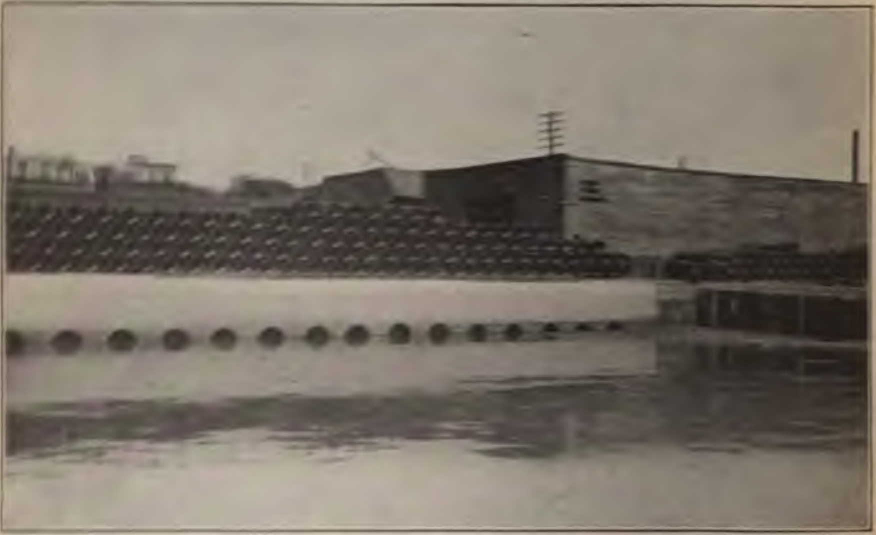


FIG. 8.—OUTLET OF SILT BASIN AT HEAD OF CANAL

In addition, the following storm overflows have also been constructed: 78-inch overflow from Nevins Street at the head of the canal; 60-inch overflow from Bond Street at the head of the canal; 42-inch storm sewer on Douglass Street; 90-inch storm sewer on Degraw Street discharging through a silt basin; 78-inch overflow from Third Avenue main sewer discharging at Second Avenue; 72-inch overflow from Bond Street main sewer discharging at foot of Bond Street.

All of these sewers bring down more or less diluted sewage and street washings during times of storm. The contents of the canal are of the vilest sort. Practically all the industrial plants on the streets adjoining the canal discharge directly into it. The following sanitary sewers empty into the canal: 18-inch sewer on Sackett Street; 18-inch sewer on President Street; 12-inch sewer on Carroll Street; 12-inch sewer on Ninth Street; 12-inch sewer on Hamilton Avenue; 48-inch sewer on Grinnell Street.

With the above exceptions, the streets which terminate at the canal have been left unsewered. The reason given is that there was not sufficient grade to drain the sewers into the mains in the streets running parallel and on either side of the canal.

Current and Deposits.—The canal is always filling up and a constant expenditure of money is required for dredging. The importance of this factor is shown by the following figures on the cost of dredging taken from various reports:

1875	550 feet west and 500 feet east of Bond Street	$2,500.00
	At Third Street bridge	250.00
1876	No dredging.	
1877	Gowanus Canal	325.00
1878	Gowanus Canal at various bridges	1,995.00
	Gowanus Canal at Sackett Street	130.00
1879	Gowanus Canal at various bridges	1,995.00
	Gowanus Canal at various localities	513.00
1880	Gowanus Canal	1,019.70
1881–1884	No records.	
1885	From Douglass Street (7 feet at low water) to Hamilton Avenue (12 feet at low water)	16,450.00
1886–1893	No records.	
1894	From Butler Street to Union Street	2,980.00
1895	Entire length and width	7,527.00
	Soundings	37.75
1896	Dredging Gowanus Canal	990.00

1897–1901	No reports available.	
1902	Dredging	$5,051 00
	Engineering expenses	106.25
	Inspection	222.50
	Total of all available records	$42,092.20

At present barges at the upper end of the canal are aground at tide. The depth of the canal is now inadequate for the passage fireboats.

The mere rise and fall of the tide have apparently no purifying effect whatever, and do not prevent the filling up of the canal with the heavier portions of the sewage. Only after heavy rainstorms, when a large amount of water is discharged from the storm sewers, is there any current noticeable.

Appearance and Odors.—The surface of the water in the canal is covered with a layer of oil, coal dust, and scum. Gases are constantly seen bubbling up through the water, especially at the upper end of the canal. In the summer time the stench at the canal is unbearable, and it is noticed at all times a block away. On certain days not only the immediate locality, but also large sections of the city on the north, west, and east, according to the direction of the wind, are seriously affected. The section on the west was formerly a handsome residence district, but in part owing to this annoyance property has steadily declined in value in the past twenty-five years.

INVESTIGATION OF THE SANITARY CONDITIONS

This investigation was undertaken to learn as much as practicable within a limited time regarding the character of the water now filling the Gowanus Canal and the nature of the pollution now entering it.

In a general way all this work has been undertaken to answer as clearly as possible the following questions:

1. Are all the odors due to the canal or are they due to manufacturing plants along the sides?

2. What is the character of the water which now fills the canal? What is the amount of organic matter present and the amount of oxygen necessary to destroy it? Are there any chemical wastes which inhibit the reduction or oxidation of putrescible substances? What is the amount of those substances which appear to be indifferent to chem-

ical changes, but which silt up the canal? How does the canal water compare with unpolluted sea water? How does it compare with the water in that part of the harbor adjoining its outlet?

3. What is the character of the entering pollution from the factories? Which is the larger factor in bringing about pollution, industrial wastes or sewage?

4. Do the ebb and flow of the tide renew the water in the canal, or does much of this water flow back and forth?

5. Is the water continually active in digesting or oxidizing and capable of rendering innocuous the pollution that comes into it?

6. What is the proportion of sewage, fresh water, and salt water in the canal; that is, what is the sewage density or the quantity of sewage per cubic foot of water?

7. What quantity of East River water would be required to dilute sufficiently the daily discharge? What quantity will be required to flush out the present contents of the canal if dredging is first resorted to?

This report will be divided into five parts:

1. The sanitary inspection.
2. Chemical and bacteriological analyses, with their interpretation.
3. Summary of existing conditions.
4. Recommendations, with calculation of the water to be pumped.
5. Summary and conclusions.

THE SANITARY INSPECTION

As careful an inspection as the time would permit was made, especial attention being paid to the incoming sewers and resulting conditions. The canal in its present state is exceedingly obnoxious, the stench even in the winter time being very disagreeable. The water is black, warm, and foul. No fish have been caught in the canal for many years. There is practically no current. The appearance of the surface and bulwarks is disgusting, especially near the sewer outlets.

The surface of the canal is covered with scum. In the upper portion (Fig. 9) this is characteristic of domestic sewage, such as grease and slime, partially disintegrated human fæces, and other organic matter. The lower portion of the canal from the Bond Street sewer outlet to Gowanus Bay is covered with unsightly patches of floating rubbish which have been accumulated by the action of the tugboats, wind, and tide. These patches consist largely of brown and yellow oily substances, which spread out in thick layers on the water surface and seem to gather up all the other floating *débris*, such as waste paper, fecal matter, melon rinds, banana skins, kitchen refuse, tin cans, broken boxes, coal dust, and other matter.

The water throughout the canal is exceedingly turbid, especially at the upper end. The turbidity is so great that the water is of a light gray color. The color becomes darker, however, and the turbidity less as the outlet is neared. In no place in the canal is it possible to see the oar blades when in a rowboat.

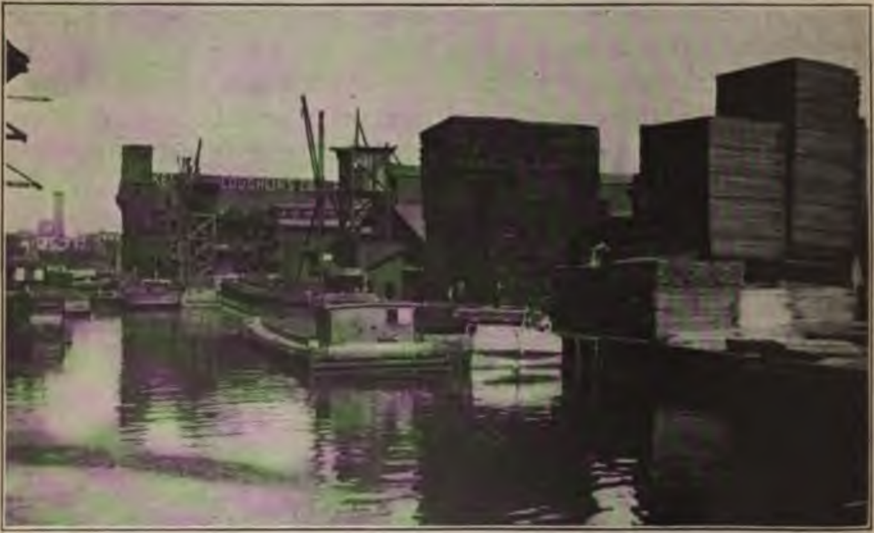


FIG. 9.—VIEW LOOKING NORTH FROM UNION STREET BRIDGE SHOWING LAYER OF SCUM IN THE FOREGROUND

Practically all the plants along the canal discharge directly into it, but the amount of sewage from these is small when compared with that contributed by the city sewers. Not only is the discharge of the sewers greater than that of the factories, but its amount and its offensive character are shown by the bad condition of that part of the canal into which it discharges. These sewers have all been named in the first part of this report. All the so-called "storm sewers" in dry weather discharge concentrated sewage, as the chemical analyses will show. The chief offender, however, is the 15-foot relief sewer at the head of the canal. During the quieter hours of the day the depth of the dry weather flow in this sewer is about 6 inches. This is continually bringing down waste paper, hair, and other sewage stuff. White scum covers the water surface in front of its outlet. Slaughterhouses drain into this sewer, for at times large quantities of blood are discharged. On wash days suds are in abundance.

A large silt basin was provided at the head of the canal to settle out the solid matter and detritus carried down in the storm sewers during heavy rains. A photograph of the silt basin is shown in Figure 8. The settling basin, however, intercepts only the coarse, heavy material. The finer material passes through and silts up the canal. In October the canal was dredged from Union Street to the head end. By February the deposit in front of the outlets filled up this section of the canal to approximately 5 feet below mean low water. In April the top of this bank was only about 3 feet below. The conditions are such that at low tide all the canal boats are aground in this portion of the canal.

The continuous discharge of the Bond Street sewer was easily detected by means of the brown and yellow oily substance already referred to. This sewer has two 36-inch outlets.

Among the more conspicuous of the private sewers are those of the gas works, which continually discharge a yellow-brown liquor. There are several of these gas plants. Their discharge outlets are from 8 inches to 12 inches in diameter and discharge full. It is to this, doubtless, that the tarry incrustation of the posts and bulwarks of the canal is due.

Much hot water is discharged into the canal. In cold weather this causes a heavy fog to hang over it. The large amount of vapor given off and the constant bubbling up of gases make the canal look boiling hot. In February the temperature of the water was 65° F. at the head of the canal. This gradually became higher on going down the canal, until at Carroll Street, where a large power plant is located, it became 70°. From here to the First Street basin the temperature rapidly became higher until 90° F. was reached. On going down the canal this soon dropped again to 70° F. and then gradually diminished, until at the entrance to the bay it became 44° F. In April the temperatures were a little higher, but varied in the same way.

The semi-liquid layer of sludge at the bottom requires merely a slight rise of temperature to cause the development of gases, which bubble up in practically the whole length of the canal. At the head end the bubbling is violent. Black solid matter arises to the surface, and discharging its burden of gas again disappears from view. The hite scum at the head end is blackened and the smell is rank, coming unbearable when the water is stirred up by the tugboats.

To sum up: The canal is an open sewer, or rather, in its present tate, practically a septic tank. There is almost no current and the ide appears to exert no flushing effect whatever. Of the plants along the canal, the gas works are doubtless the chief offenders. The trouble, however, is due largely to the discharge from the city sewers, which discharging into a body of quiet water cause heavy deposits to be formed. The canal water being stagnant and devoid of oxygen, the deposits putrefy and are the seat of the nuisance. These conclusions are borne out by the chemical and bacteriological analyses.

CHEMICAL AND BACTERIOLOGICAL ANALYSES

Before taking up the regular analytical work, it was thought best to ascertain from a few preliminary samples from various portions of the canal the character of the water to be analyzed.

Two of these samples, one taken at the Union Street bridge near the head of the canal, and the other at the Ninth Street bridge near the lower end, gave interesting results. The first was strongly indicative of sewage, the other of industrial wastes. Tests were made for acidity. The first was found to be neutral to litmus, acid to phenolphthalein, and alkaline to methyl orange. The other, although neutral to litmus, was acid to both phenolphthalein and methyl orange. Both were decidedly turbid and had much matter in suspension. The behavior on evaporation on the steam bath and on ignition also deserves attention. The first blackened readily on ignition and gave off a strong sewage odor. The second on the bath gave off an acetic acid odor; on ignition the solid matter decrepitated, and the odor was at first leathery, then like fertilizer, and finally very offensive. The substance burned with great difficulty, indicating vegetable carbon. Both samples contained a large amount of chlorine and sulphates, the second, however, in much greater proportions than the first.

Pollution by the gas plants was particularly evident, both from the odor of the water and from the color and behavior of the precipitate formed on nesslerization. This, instead of being of the reddish color characteristic of ammonia, was a heavy, curdy precipitate, canary yellow in color, the reaction indicating amines.

It was decided in the regular series of analyses to make the following six tests chemically: oxygen consumed, total organic nitrogen, free ammonia, dissolved oxygen, turbidity, and chlorine. From ratios of these six in sea water and sewage an attempt has been made to determine the degree of pollution of the canal.

Method of Taking Samples. — In obtaining samples care was taken to choose representative points along the canal and to guard against accidental or abnormal conditions. The samples were taken from a rowboat at different depths and at different points in a cross-section of the canal. This was done by letting up and down a large bottle with a double perforated stopper while rowing across the canal. The contents of the bottle were then emptied into a pail and a liter bottle was filled from the mixture. This method gave a sample which was fairly representative of the cross-section of the canal from which it was taken.

As soon as the samples for the entire canal were obtained they were immediately taken to the Mount Prospect Laboratory, which was within twenty minutes' ride from the canal.

Methods of Chemical and Physical Analysis. — With the exception of the test for turbidity, the methods of chemical and physical analysis were those recommended by the Committee on Standard Methods of Water Analysis. The oxygen consumed was determined by the five-minute-boil method, the nitrogen content by the Kjeldahl Process, and the free ammonia by direct nesslerization. The turbidity was determined by means of the Jackson turbidimeter. The observation was made by pouring the sample of water into the tube until the image of the candle disappeared. The turbidity was then read from a graduation on the side of the tube. This graduation corresponded to the turbidity produced in distilled water by a certain number of parts per million of silica standard.

Methods of Bacteriological Analysis. — The media used for this work were standard media, made according to the procedure established by the Committee on Standard Methods of the American Public Health Association. The determinations were made for total count per cubic centimeter by plating on gelatin at 20° C., body temperature count on litmus lactose agar at 37° C., and tests on gas production, the latter being the only tests for *B. coli* considered necessary. In plating, two dilutions, one to 1,000 and one to 10,000, respectively, were made.

In the first series of analyses, use was made of the method of direct oculation of 1 c.c. of the canal water into the Smith fermentation tube, but in a second series this method was abandoned in favor of Jackson's new bile media.[1]

Tests for Bacillus coli. — In the fermentation tubes 25 per cent. to per cent. gas was considered indicative of the colon bacillus, and ositive record was made if the other tests were favorable, *i.e.*, if proportion of CO_2 fell within the right limit. This limit was from per cent. to 40 per cent. absorption by caustic.

FIRST SERIES OF ANALYSES

Dissolved Oxygen. — Examinations of the water for dissolved oxygen were carried on simultaneously with the sanitary inspection. About thirty samples were taken at intervals along the canal from the head end to Hamilton Avenue, and, with the few following exceptions, negative results were obtained. Four surface samples also were taken from the East River, and the results of analysis are given in the second table below.

GOWANUS CANAL

No.	Place of collection.	Temperature.	c.c. oxygen per liter.	Per cent. saturation.
1	Entrance to power house basin, 4 P.M.	80° F.	1.14	20.2
2	East pier, Third Street bridge, 4 P.M.	70° F.	0.58	9.3
3	Entrance power house basin 9 A.M. next day	90° F.	1.54	30.4
4	Just below basin	90° F.	1.05	20.7
5	Above Third Street bridge	70° F.	1.03	16.5
6	Below Third Street bridge	70° F.	1.01	16.2
7	20 feet below Third Street bridge	70° F.	0.73	11.7
8	75 feet below Third Street bridge	70° F.	0.30	4.8
9	100 feet below Third Street bridge	70° F.	0.00	0.0

EAST RIVER

No.	Place of collection.	Temperature.	c.c. oxygen per liter.	Per cent. saturation.
1	Buttermilk Channel, 200 feet from Brooklyn side	35° F.	7.50	77.4
2	Mid-stream opposite Governor's Island	30° F.	7.58	74.5
3	Return trip, same as 2	30° F.	7.95	78.0
4	Buttermilk Channel, 75 feet from Brooklyn side	34° F.	7.90	80.5

---

[1] For description, see Biological Studies by the Pupils of **William Thompson Sedgwick**, Boston, 1906, pp. 292–299.

The other results of the first series are shown in tabulated form in Table I.

Analysis of the Sludge.—Samples of the sludge which appeared to form a semi-liquid layer on the bottom were analyzed for total solids, oxygen consumed, and total organic nitrogen Inasmuch as the method of taking samples was crude and allowed some water to mix with the sludge, the density was changed. The results are therefore expressed in ratios for comparison.

Location of sample.	Oxygen consumed: total nitrogen.	C + N: total solids.
Head of canal	16.2	1 : 1.9
150 feet below head	13.0	1 : 2.0
300 feet below head	9.8	1 : 2.2
Opposite Degraw Street	11.0	1 : 2.1
Entrance First Street basin	10.3	1 : 3.3
Entrance Fifth Street basin	7.0	1 : 3.1
Opposite Bond Street	13.0	1 : 3.5

Experiments were made on the temperature necessary to develop gases from the sludge. Ten c.c. of the various samples were diluted to about 60 c.c. and placed on ice. After standing on the ice for several hours, all the foul air possible was exhausted and replaced by fresh air. The bottles were then set back into the ice chest and allowed to remain there over night. The temperature of the ice chamber was 2° C. At this temperature no sewage odor was noticeable. The samples were then allowed to stand in the room, and their condition was noted from time to time. No. 1 became offensive at 12° C.; Nos. 2, 3, and 4 at 12.5° to 13° C. Sample No. 5 contained a quantity of tarry matter and required a temperature of 14° C. to become offensive. The samples were then slowly warmed. At 20° C. the odor was very strong. At 23° C. the stench became vile and unbearable, especially in the first three samples.

A sample of the incrusting substance on the bulwarks was also taken. On analysis this was found to be a tarry waste product of the gas works.

SECOND SERIES OF ANALYSES

The first series of analyses was made in February, 1906. The second was carried out in April. This series included a sample of

TABLE I. — SHOWING ANALYSIS OF SAMPLES TAKEN FROM THE GOWANUS CANAL, FEBRUARY 3, 1906

CHEMICAL ANALYSIS (Parts per Million)

No.	Place of collection.	Temperature.	Turbidity. (Parts per million of silica.)	Nitrogen as		Chlorine.	Oxygen consumed.	Number of bacteria per c.c., 48 hours at 20° C.	B. Co
				Total organic nitrogen.	Free ammonia.				In 1 c.c.
1	Head of canal	. .	420	50.4	17.0	300	95.3	3,220,000	+
2	Just below Degraw Street	. .	265	44.0	17.0	1,400	64.0	1,440,000	+
3	Just below Carroll Street	. .	100	12.2	7.0	4,000	46.4	252,000	+
4	Entrance First Street basin	90° F.	105	10.4	4.4	5,700	36.8	99,000	+
5	Entrance Fifth Street basin	. .	125	8.2	6.6	5,900	43.2	171,000	+
6	Opposite Bond Street	. .	95	10.4	4.4	6,400	28.8	168,000	+
7	In Sixth Street basin	. .	160	14.7	6.1	6,200	45.6	217,000	+
8	Entrance Eighth Street basin above tartar factory	. .	100	15.9	3.3	6,700	42.4	217,000	+
9	Below Ninth Street	65° F.	90	13.9	5.3	7,000	35.2	254,000	+
10	Below Hamilton Avenue	55° F.	110	4.8	4.8	7,450	56.8	90,000	+
11	Entrance to bay	44° F.	120	13.5	5.7	7,500	102.4	69,000	+

NOTE. — Samples were taken at time of flood tide.

sewage taken from a manhole at the corner of Nevins and Butler Streets, and fifteen samples taken from different portions of the canal. The sample from the manhole was taken on Saturday morning, April 14. The depth of flow in the sewer was 6 inches. The samples from the canal were not taken until Monday morning, April 16. A heavy rain fell on Saturday night and Sunday morning, and the canal water was well stirred up.

In this series samples were analyzed both filtered and unfiltered, and the test for total solids was added. In the latter the sodium chloride present rapidly took on moisture from the air, and for that reason the tests for total and dissolved solids are rough and therefore of not much importance. The results of the second series are given in tabulated form in Table II.

Tests for putrescibility of the sewage and the degree of dilution necessary were made by the methylene blue test. This was done by adding 1 c.c. of a 0.1 per cent. solution of methylene blue to a half pint of the different dilutions of the sewage with tap water. These tests showed a dilution of one part sewage to fifteen parts water to be necessary for a stable mixture.

INTERPRETATION OF THE RESULTS

Interpretation of Figures Obtained.—The tabulated results give evidence of the amount and nature of the pollution. Tables, however, show more when they are represented graphically. Therefore to aid in the interpretation the results obtained have been plotted. The construction of the diagrams needs no explanation. The curves are striking and interesting. With the exception of those for chlorine and total and dissolved solids, they all have a general downward tendency, which shows the effect of dilution with sea water. The curves for the first series are much smoother than those for the second, because the second series of samples was taken after the canal had been stirred up by a heavy rainfall. It will be interesting to examine the curves and to account for the variations which occur.

Total Organic Nitrogen.—In the first series (Fig. 10) this curve falls rapidly until Bond Street is reached. Here it again rises, reaching a maximum opposite the Tartar Chemical Company.

In the second series (Fig. 12) there is a general decrease. The curve drops rapidly at the entrance to the First Street basin. This is

TABLE II. — SHOWING ANALYSIS OF SAMPLES TAKEN FROM THE GOW[illegible] CANAL.

CHEMICAL ANALYSIS (Parts per Million)

No.	Place of collection.	Temperature.	Turbidity (parts per million of silica).	NITROGEN AS				Total solids.	Suspended solids.	In solution.	Chlorine.	OXYGEN CONSUMED.			of bacteria 48 hours C.			
				Organic nitrogen			Free ammonia.					In solution.	In suspension.	Total.				
				In solution.	In suspension.	Total.												
	Sewage taken from manhole, corner Nevins and Butler Streets, April 14, 1906, 9 A.M.	. .	475	51.8	19.5	71.3	36.0	1,860	1,220	640	230	116.4	48.6	165.0	3,120,000	+	+	+
1	Head of canal	77°.0 F.	380	30.5	19.3	49.8	24.0	1,160	260	900	350	42.3	33.2	75.5	—	+	+	+
2	Opposite Sackett Street	77°.0 F.	320	17.8	25.7	43.5	11.0	3,580	320	3,260	1,010	48.6	37.4	86.0	1,680,000	+	+	+
3	Below Carroll Street	99°.5 F.	1,000	8.8	22.5	31.3	4.0	11,980	480	11,500	4,600	17.6	91.7	109.3	1,280,000	+	+	+
4	Entrance First Street basin	101°.3 F.	150	9.8	1.6	11.4	3.0	10,720	1,260	9,460	4,700	16.2	9.2	25.4	1,030,000	+	+	+
5	Above Third Street	91°.4 F.	400	5.3	12.8	18.1	4.3	12,380	620	11,760	4,600	17.6	67.8	85.4	685,000	+	+	+
6	Opposite Fifth Street basin	73°.4 F.	265	24.8	12.8	37.6	4.0	10,540	2,440	8,140	4,850	14.1	32.4	46.5	670,000	+	+	+
7	Below Bond Street	. .	385	8.8	4.8	13.6	4.0	15,540	6,600	8,940	3,890	20.4	57.1	77.5	643,000	—	—	+
8	Opposite Sixth Street basin	. .	155	7.8	1.0	8.8	4.0	7,100	380	6,720	3,100	16.9	7.1	24.0	360,000	+	—	+
9	Above Seventh Street basin	55°.4 F.	160	8.3	2.6	10.9	3.5	11,300	1,820	9,480	4,100	12.7	8.5	21.2	228,000	+	+	+
10	Below Seventh Street basin	. .	175	19.9	6.4	26.3	2.5	9,500	180	9,320	4,200	12.7	7.0	19.7	223,000	+	+	+
11	Below Ninth Street	. .	290[1]	6.8	3.2	10.0	6.0	9,480	780	8,700	4,480	14.8	4.9	19.7	219,000	+	+	+
12	Above Eleventh Street basin	. .	90	7.1	3.2	10.3	2.5	21,040	1,660	19,380	4,050	16.2	9.2	25.4	—	+	+	+
13	Above Hamilton Avenue (near sewer outlet)	. .	85	0.7	0.4	1.1	8.5	17,720	540	17,180	5,100	6.9	3.0	9.9	—	+	+	+
14	Below Hamilton Avenue (opposite sewer outlet)	51°.8 F.	80	6.0	4.8	10.8	2.0	24,320	12,360	11,960	5,200	13.3	5.0	18.3	206,000	+	+	+
15	Entrance to bay	50°.0 F.	70	. .	. .	9.3	3.5	19,900	6,360	13,540	6,060	7.1	7.7	14.8	335,000	+	+	+

NOTE. — Samples taken on a rising tide.

[1] Milky.

due to the large amount of clean water discharged from the power house. At Third Street the curve rises to what would be a point on the normal dilution curve. Opposite the Fifth Street basin there is a rapid rise, which is due to a stirring up of the water at that point by tugs at the time that the sample was taken. The curve then again drops rapidly, but not to what would be a point on the normal dilution curve. The Bond Street sewer enters here. There is then a gradual drop until we arrive at the Tartar Chemical Company, where there is a sudden increase. Above Hamilton Avenue bridge there is another quick drop. A glance at some of the other curves shows that this drop is general. On the other side of the bridge, however, the curve rises again.

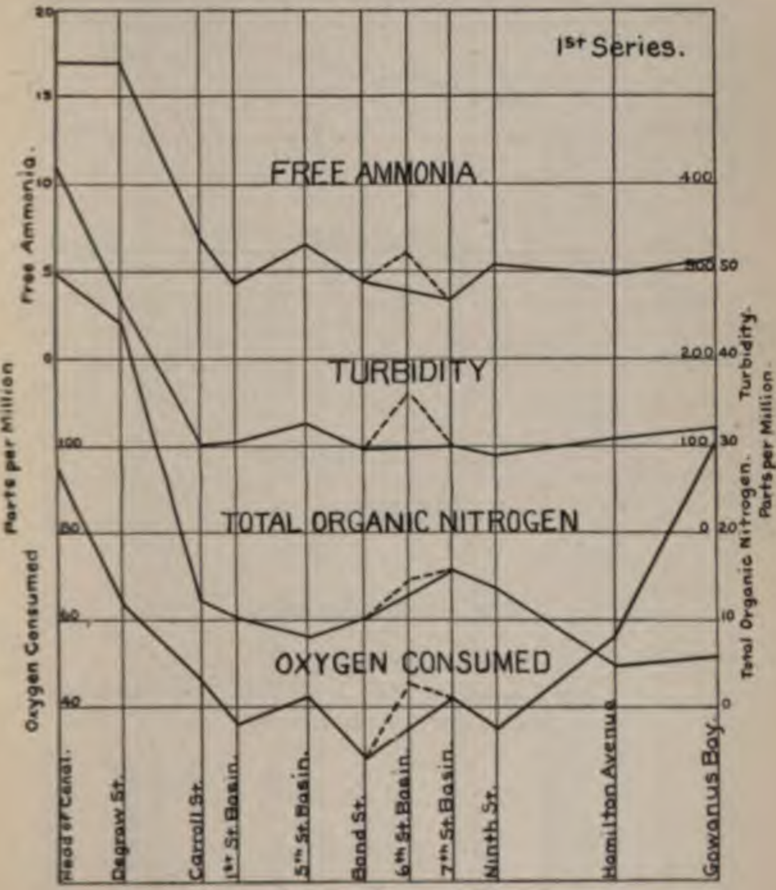


FIG. 10

A sewer enters here. There is then a slow, gradual decrease, indicating lution with sea water.

T e curves for suspended and dissolved organic nitrogen are similar at for the total organic nitrogen, and no special comment on them essary.

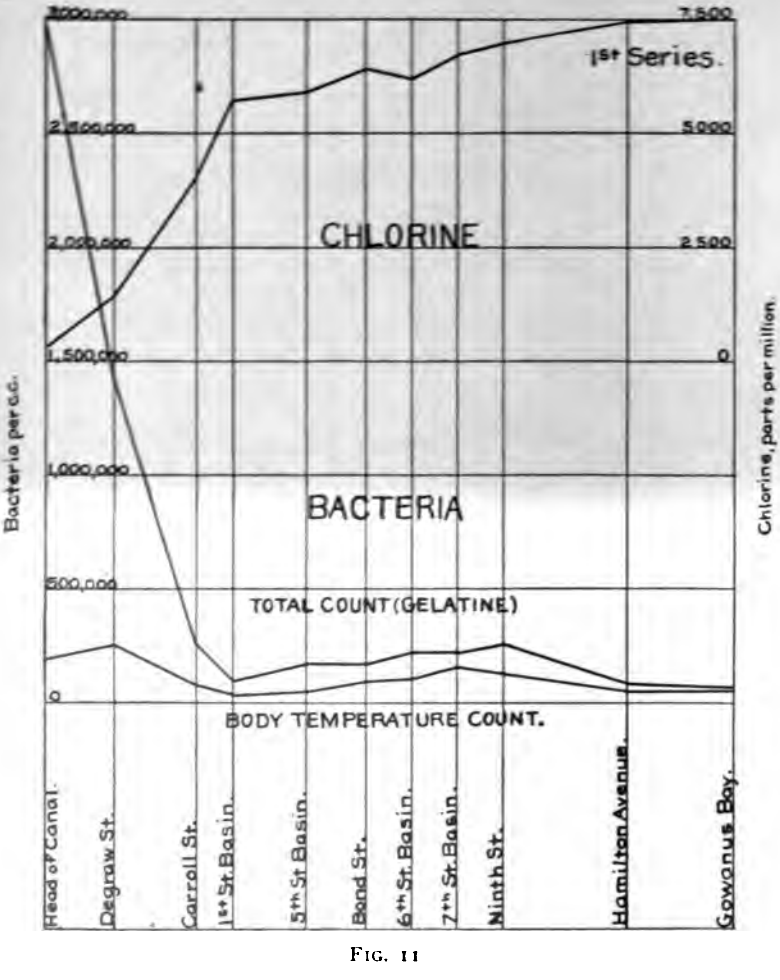


FIG. 11

Oxygen Consumed. — In the first series (Fig. 10) this curve falls off rapidly until after Bond Street is passed. Opposite the Fifth Street basin there is an increase, probably due to coal dust. The most conspicuous part of the curve, however, is the steady and rapid increase after the starch factory at Ninth Street is passed.

In the second series (Fig. 13) there is an increase at the start, with a quick rise at Carroll Street. A glance at the turbidity curve will show that this rise is due to the water having been stirred up. There is a quick drop at the First Street basin and a quick rise again at Third Street. The turbidity also is high at this point. The apparent drop at the Fifth Street basin was unexpected, since the nitrogen is high at that point. A further study of the diagrams, however, will show that the oxygen consumed is also absolutely very high.

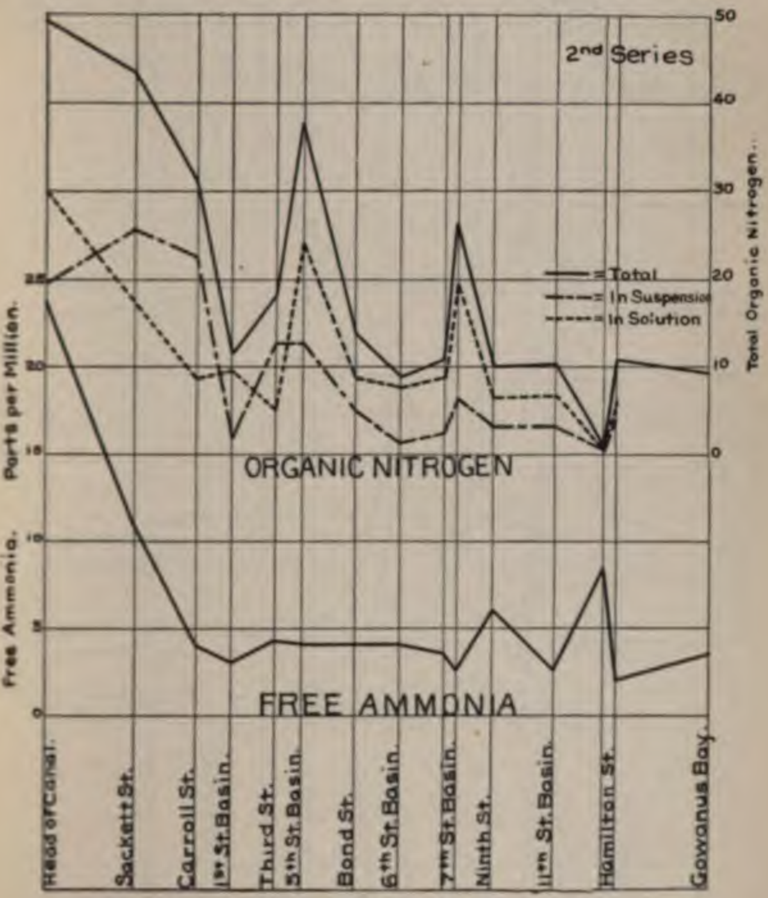


Fig. 12

After passing Bond Street the curve has a downward tendency, with only a slight rise beyond Ninth Street. This is significant. The samples were taken on a Monday morning, and there was no pollution

by factory. Most of the material which had been dis
rged on Saturday night was flushed out by the heavy flow of stor
ter on Saturday night and Sunday.

The same drop just above the Hamilton Avenue bridge alread

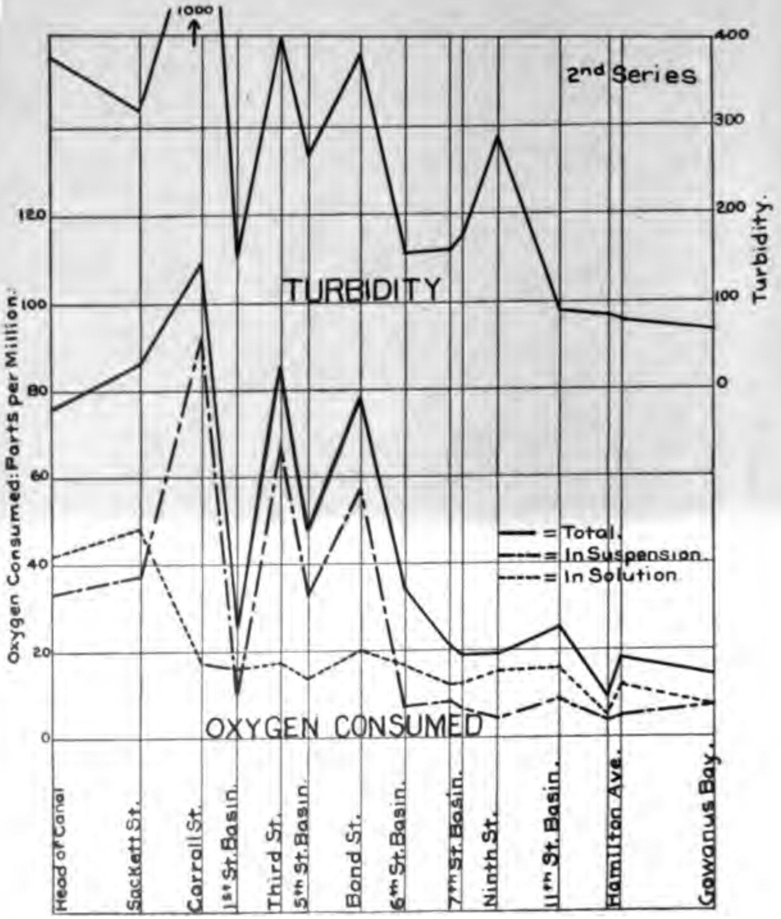


FIG. 13

mentioned in the discussion of the organic nitrogen curve is conspicuous here. Below Hamilton Avenue the curve rises again and then decreases gradually.

Turbidity.— In both series of analyses (Figs. 10 and 13) this curve seems to vary with the dilution and shows that sedimentation has taken place all the way down, being interrupted occasionally by the stirring up of the water. The curves for turbidity are strikingly similar to those for organic nitrogen and for oxygen consumed.

The remaining curves simply reënforce points brought out in the curves already discussed and require no especial explanation. We are, therefore, ready to consider the various curves simultaneously. Sample No. 1 shows at once that we have much accumulated solid matter which is constantly stirred up. The nitrogen is very high. This means that there is an additional supply of organic matter there, which, being constantly stirred up, keeps in circulation, but is never carried out. This

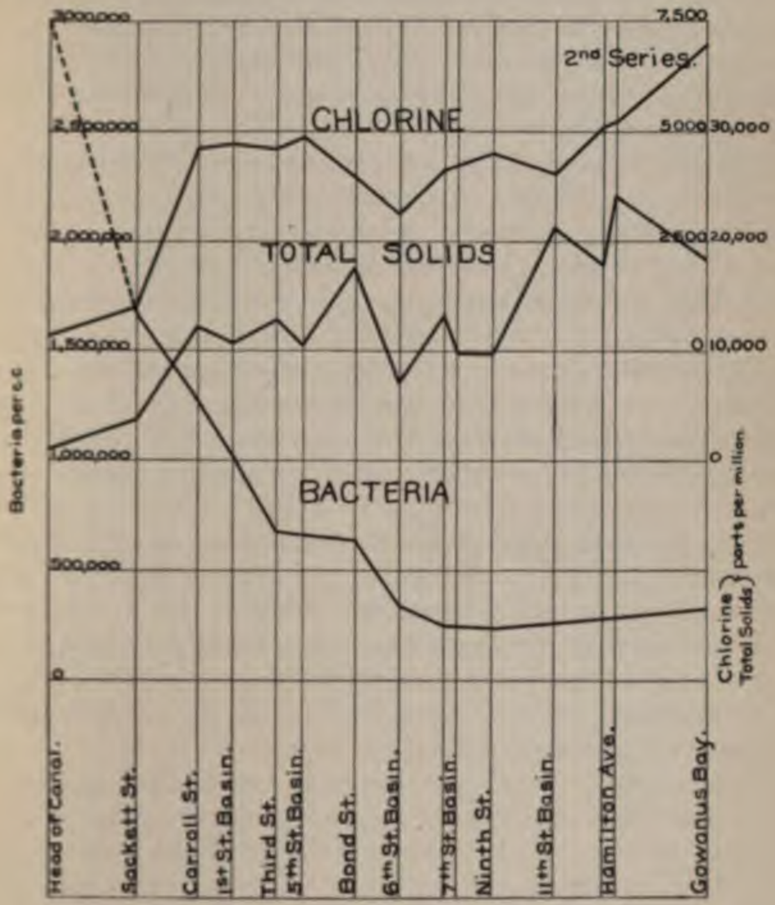


FIG. 14

the way down the canal. The fact that the chlo- at rmal — twice what it ought to be — shows a mixture at the sewage. In the first five samples the ratio of ed nitrogen to total nitrogen gives good evidence of septic action. organic nitrogen is converted into free ammonia, there are two ces noticeable: the ratio of free ammonia to total organic nitrogen he ratio of oxygen consumed to total organic nitrogen becomes er. Both carbon and nitrogen are going down, but the nitrogen s down much faster.

From a bacteriological standpoint, the low count at body temperature compared with the high total count in water from the head of the canal is interesting. It indicates tha ic action is taking place and corroborates the evidence mentione last paragraph.

The total number of bacteria very rapidly on going down the canal, reaching in the first series of analyses (Fig. 11) a minimum opposite the First Street basin. In tl second series (Fig. 14) this minimum is not reached until the Seventh Street basin is reached, showing the flushing effect of the st m water. A glance at the curves for chlorine shows that this ra lecrease in the total bacteria count is due to dilution.

Below the First Street basin the number of bacteria does not increase materially, thus substantiating the evidence that most of the pollution below this point is due to industrial wastes.

The discharge of the Bond Street sewer seems to increase the oxygen consumed, but not the nitrogen. The bacteria go down, and this sewage seems to be an antiseptic, non-nitrogenous substance, in appearance quite similar to gas plant wastes.

Lateral Basins. In the first series, to ascertain how the water in the basins compared with that in the main part of the canal, a sample was taken from one of these. This is represented in the curve (Fig. 10) by dotted lines. The result is significant. A glance at the curves shows that free ammonia, oxygen consumed, total organic nitrogen, turbidity, and the total bacteria count are higher than in the adjacent portion of the main canal, while the chlorine and the body temperature count are lower. This is characteristic of a dead end. The depression in the chlorine curve shows that the tide exerts no flushing effect, and the low body temperature count shows that the water in the basin is stagnant.

Variations between the Two Series. — The first series of analyses was carried on at a time when there was no rain. The second series of samples was taken after the run off from a heavy rainfall had stirred up the contents of the canal. On comparing the two sets of curves, the reader will see that in general they cross one another several times, that the curves of the second series are very ragged, plainly giving evidence of a general stirring up. At the uppermost point of the canal, however, the second series shows less pollution than the first. The curves soon cross, however, and in general the first series of curves is lower than the second. This is due to the large volume of storm water which had pushed the sewage at the head end farther down. The turbidity curve for the second series is entirely above that for the first series.

Difference in Character of Pollution in Various Parts of the Canal.— The upper part of the canal is badly polluted by sewage. At the lower end the pollution is largely industrial wastes mixed with more or less sewage.

As a rule, the amount of nitrogen present varies directly with the amount of sewage. The other constituents of sewage vary with the nitrogen. Therefore when the nitrogen is greatly increased without a corresponding increase in the other sewage substances it is an indication of industrial wastes. This is exactly what happens in that portion of the canal opposite the Tartar Chemical Company. On talking with one of their employees, we learned that crude argol is digested with sulphuric acid, and that the waste product is an acid sludge running high in sulphates and nitrogen.

In the first series, below Ninth Street the oxygen consumed curve went up rapidly. In the second series the curve had a downward tendency. The starch factory, not running on Sunday, had no waste to discharge at that time. The abnormal values for the oxygen consumed are probably due to gluten in the wastes discharged by the starch factory.

Another interesting point, characteristic of both series of curves, is the sudden drop in most of the curves just above Hamilton Avenue. It is significant that not only the organic nitrogen, oxygen consumed, turbidity, and total solids, but the bacteria also go down. This looks like precipitation. The curves for ammonia and chlorine, on the other hand, show a slight increase. Immediately above this point is a coal gas plant, which evidently uses lime to recover its ammonia. The waste from the Tartar Chemical Company, which is carried along by the tide, comes into contact with the gas plant waste, and calcium sulphate is probably precipi ed, carrying down with it nearly all the other suspended matter.

The rapid decrease in bacteria below Bond Street gives evidence of iseptic action. A glance at the diagrams will show that, although nitrogen and carbon go up at that point, the ammonia remains same, and the bacteria count goes down and stays down. The that the ratio of carbon to nitrogen is greatly increased shows that pollution from the Bond Street sewer is largely of a carbonaceous ture.

Although taken at different times, and thus representing different conditions, there is no essential difference in the results obtained from the two series. The second series simply reënforces the first and justifies drawing the following conclusions:

The canal is highly polluted with house drainage and industrial wastes. The city sewers are the chief source of the trouble. The organic animal matters contained in the sewage are more easily susceptible to putrefactive influences than is the vegetable matter in the industrial wastes. The tide exerts very little flushing effect in the main body of the canal, and practically none whatever in the dead ends or basins.

SUMMARY OF EXISTING CONDITIONS

The table below will show the immense pollution of the canal. The figures for sea water were taken from the Report of the Committee on the Charles River Dam. The figures for Boston tap were taken from the Massachusetts Board of Health Report for 1904. Those for harbor water are the average of the accompanying table, compiled from analyses made by Dr. Jackson for the New York Bay Pollution Commission.

Sample.	Free NH_3.	Organic nitrogen.	Oxygen consumed.
From head of canal	24.0	50.1	85.4
Sea water	0.012	0.16	. .
Boston tap	0.015	0.29	3.9
Harbor water	0.534	1.28	. .

The figures speak for themselves. The pollution of the canal is almost fifty times that of the harbor.

TABLE III.—SHOWING ANALYSIS OF SAMPLES FROM THE EAST RIVER, MADE BY DR. DANIEL D. JACKSON FOR THE NEW YORK BAY POLLUTION COMMISSION

CHEMICAL ANALYSIS (Parts per Million)

No.	Date of collection.	Place of collection.	Temperature.	Turbidity (parts per million of silica).	Tide.	Nitrogen as			Chlorine.	Dissolved oxygen; c.c. per liter.	Number of bacteria per c.c., 48 hours at 20° C.	B. Coli		
						Albuminoid ammonia.	Free ammonia.	Nitrites.				In 0.1 c.c.	In 1 c.c.	In 10 c.c.
	April 1, 1905, A.M.													
1	9.55	Off Battery (bottom)	—	7	Flood	0.27	0.31	. .	11,800	8.62	4,280	+	+	+
2	10.00	Off Battery (surface)	—	10	Flood	0.27	0.32	. .	6,100	8.84	6,250	+	+	+
3	10.05	East River off Pier No. 15	. .	10	Flood	—	—	. .	4,800	. .	4,410	+	+	+
4	10.10	Under Manhattan Bridge	—	8	Flood	0.32	0.49	. .	9,600	. .	8,460	+	+	+
	Jan. 30, P.M.													
9	12.35	Off Battery and Governor's Island (midstream, 5 feet from surface)	37°.0 F.	45	Flood	0.78	0.97	0.012	7,600	8.50	1,510	+	+	+
8	12.30	Off Battery and Governor's Island (midstream, 40 feet from surface)	37°.0 F.	30	Flood	0.73	0.84	0.015	11,600	—	920	+	+	+
7	12.20	Off Battery and Governor's Island (midstream, 80 feet from surface)	37°.0 F.	35	Flood	0.73	0.75	0.012	12,700	—	760	+	+	+
12	3.15	Off Battery and Governor's Island (midstream, 5 feet from surface)	. .	18	Ebb	0.73	1.11	0.013	9,100	8.60	1,200	+	+	+
11	3.10	Off Battery and Governor's Island (midstream, 40 feet from surface)	. .	20	Ebb	0.67	0.70	0.012	13,100	—	740	+	+	+
10	3.00	Off Battery and Governor's Island (midstream, 80 feet from surface)	. .	25	Ebb	0.71	0.72	0.011	13,200	—	540	+	+	+
		Series No. 6												
27	3.38	Off Battery	33°.0 F.	6	. .	0.28	0.26	. .	8,300	. .	7,280	+	+	+
28	3.45	Off Pier No. 6, East River	33°.5 F.	—	. .	—	—	. .	8,400	. .	14,100	+	+	+
29	3.55	Off Pier No. 13, East River	33°.5 F.	10	. .	0.24	0.41	. .	8,600	. .	18,400	+	+	+
30	3.58	Off Pier No. 20, East River	33°.5 F.	5	. .	0.21	0.37	. .	8,900	. .	12,600	+	+	+
31	4.00	Off Pier No. 28, East River	33°.5 F.	7	. .	0.40	0.52	. .	8,400	6.98	15,300	+	+	+
32	4.05	Off Pier No. 23, East River (Brooklyn)	33°.5 F.	—	. .	—	—	. .	8,600	. .	4,300	0	0	+
33	4.15	Off Atlantic Docks, Buttermilk Channel	33°.5 F.	8	. .	0.25	0.46	. .	8,600	6.54	10,400	+	+	+

Absolute Values Compared with Sewage. — Below is given a table comparing the canal water with several well-known sewages.

Place.	Date.	Free NH_3.	Organic Nitrogen.		Chlorine.	Oxygen consumed.	Bacteria per c.c.
			Total.	Solution.			
ooklyn	April 14, 1906	36.0	71.3	51.8	230.0	165.0	3,120,000
Boston	Average	19.9	23.0	10.5	1,300.0	45.0	3,000,000
Lawrence	Maximum, 1904	71.8	39.2	20.6	163.9	65.4	3,020,000
Lawrence	Minimum, 1904	41.6	12.1	5.4	82.7	38.4	1,440,000
Lawrence	Average, 1904	51.5	18.3	8.7	123.1	48.6	1,930,000
Andover	June, 1902	103.0	51.4	20.0	678.0	107.7	3,680,000
Andover	Average, 1902	74.6	35.8	17.0	164.7	76.7	3,750,000
Head of canal	Mean	24.0	50.1	30.5	325.0	85.4	3,100,000
Opposite Fifth Street basin .	Mean	7.5	37.6	24.8	4,850.0	46.5	670,000
Below Hamilton Avenue . .	Mean	3.5	7.8	4.5	6,325.0	18.3	200,000

From the above table it is evident that the water at the head of the canal is about two-thirds as strong as Brooklyn sewage. It is more than twice as strong as Boston sewage; its strength is three times that of Lawrence sewage and about equal to that of Andover, which is one of the strongest in Massachusetts.

The sample taken opposite the Fifth Street basin corresponds to the strongest Lawrence sewage in 1904, and to the average Andover sewage for 1902.

At Hamilton Avenue the water contains about one-tenth of Brooklyn sewage, and is about one-half the strength of the minimum Lawrence sewage in 1904.

RECOMMENDATIONS, WITH CALCULATION OF THE AMOUNT OF WATER TO BE PUMPED

Recommendations. — The Gowanus Canal is in a very poor sanitary condition, and measures should be taken to abate this nuisance as soon as possible. In the study from which this abstract is taken, the methods of dealing with this problem came under two heads, those which involve some method of flushing the canal and those involving a sewerage system for the locality. These were taken up and considered in detail by the writer's colleague in the investigation — Mr. Norman P. Gerhard, now assistant engineer, Board of Water Supply, City of New York.

It is not the purpose of this abstract to suggest a remedy, since the problem has already received the attention of the engineers of the Borough of Brooklyn and a flushing tunnel from the East River to the head of the Gowanus Canal is now under construction. The writer will therefore confine himself, as he did in the original thesis, to a calculation of the amount of water to be pumped under various methods of flushing the canal.

Calculations were made in two cases. In the first it was assumed that flushing alone would be considered and enough water pumped in to render the sewage matter innocuous and to create a current strong enough to prevent it from settling out. In the second case it was assumed that intercepting sewers would be built and the district sewered, enough water being pumped to cleanse the canal in a reasonable length of time, and thereafter create a small current sufficient to prevent it from becoming stagnant.

Both methods require that the present sludge deposits should be removed by dredging. A tremendous quantity of water would be required to give sufficient scouring velocity to remove the sludge. Even so, the present nuisance at the head of the Gowanus Canal would only be transferred to its branch dead ends and into Gowanus Bay. The power of New York Harbor to dispose of the sewage that comes into it is already being questioned. The Harbor Pollution Commission found that the tide has little effect in eliminating the pollution of the bay, and that the water seems incapable of renewing its supply of oxygen. It is evident then that it would be unwise to pollute the harbor still more by flushing into it the sludge which has accumulated in the Gowanus Canal.

Calculation of the Amount of Water to be Pumped. — We have, therefore, to consider for calculation two possibilities, the daily dilution of the total amount of sewage discharged into the Gowanus Canal, and the remedying of its present unsanitary condition in case an intercepting sewer should be built. The object of these calculations is to compute the required dilution from figures obtained by chemical analyses. Before proceeding with these calculations it is necessary, however, to determine first the proportion of sewage at present in the canal.

Sewage Density. — This may be defined as the proportion of sewage per unit volume. The canal water can be considered as a mixture of three separate iids: sewage, terrestrial (*i.e.*, surface + ground) water, and harbor water. The object of these calculations is to obtain absolute values for each of these three. In making these calculations, use has been made of the usual method of determining by the chlorine ent in a mixture of two such liquids the proportion of each. This two independent equations. A third equation was obtained by eans of the nitrogen values. The method of attack was as follows:

Consider a section in the canal of unit dimensions. Let

x = portion of sewage;
y = portion of terrestrial water;
z = portion of harbor water;
C = total chlori
N = total nitrogen;
c_1 = chlorine in sewage;
c_2 = chlorine in terrestrial water;
c_3 = chlorine in harbor water;
n_1 = nitrogen in sewage;
n_2 = nitrogen in terrestrial water;
n_3 = nitrogen in harbor water.

We then have the equations:

$$x + y + z = 1. \tag{1}$$

$$xc_1 + yc_2 + zc_3 = C. \tag{2}$$

$$xn_1 + yn_2 + zn_3 = N. \tag{3}$$

To solve we must find or assume values for the constants. The pollution of the canal is so great that the amount of nitrogen in terrestrial water when compared with it is practically zero. Considering the proximity to the sea, we may assume 10 as an average value of the chlorine content of this water.

From the table given above, showing the analyses made by Dr. Jackson for the New York Bay Pollution Commission, it appears that average figures for the nitrogen and chlorine content of harbor water may be assumed at 1 and 8,600, respectively.

Considering the particular problem on hand, we therefore have the following constants:

$$c_1 = 230; \quad c_2 = 10; \quad c_3 = 8{,}600;$$

$$n_1 = 107; \quad n_2 = 0; \quad n_3 = 1.$$

Substituting these values in the above equations, the two following tables, showing the proportion of sewage, terrestrial water, and harbor water at different sections in the canal, have been computed:

FIRST SERIES

No. of sample.	C.	N.	PROPORTION OF		
			Sewage.	Terrestrial water.	Harbor water.
1	300	67.4	.63	.36	.01
2	1,400	61.0	.57	.42	.01
3	4,000	19.2	.18	.35	.47
4	5,700	14.8	.13	.19	.68
5	5,900	14.8	.13	.14	.73
6	6,400	14.8	.13	.08	.79
7	6,200	20.9	.19	.03	.78
8	6,700	19.2	.17	.03	.80
9	7,000	19.2	.17	.03	.80
10	7,450	9.6	.08	.09	.83
11	7,500	19.2	.17	.03	.80

SECOND SERIES

No. of sample.	C.	N.	PROPORTION OF		
			Sewage.	Terrestrial water.	Harbor water.
1	350	73.8	.68	.31	.01
2	1,010	54.5	.51	.35	.14
3	4,000	35.3	.32	.05	.63
4	4,700	14.4	.13	.33	.54
5	4,000	22.4	.13	.29	.58
6	4,850	41.6	.38	.05	.57
7	3,800	17.6	.16	.36	.48
8	3,100	12.8	.12	.51	.37
9	4,100	14.4	.13	.38	.49
10	4,200	28.8	.26	.24	.50
11	4,400	16.0	.15	.33	.52
12	4,050	12.8	.12	.42	.46
13	5,100	9.6	.08	.34	.58
14	5,200	12.8	.12	.28	.60
15	6,950	12.8	.11	.10	.79

Quantity of Water to be Pumped.—One condition e d lution required to make sewage inoffensive is that ting water shall have a sufficient supply of free oxygen. The nts made on Brooklyn sewage for putrescibility showed the of 1 : 15 to be necessary.

sewage discharged into the canal daily is estimated to be o cubic feet. The amount of water, therefore, to make this uous is 793,000 × 15 = 11,895,000 cubic feet per day. Allowing tor of safety of 2, there would be required 23,800,000 cubic feet er day.

Supposing no sewage is allowed to enter the canal and its contents are to be flushed out in thirty days, can calculate the necessary quantity of water as follows:

The average sewage density of the c al, as computed in the above tables, is 0.25. Therefore $x = \frac{10,00 \quad 000 \, (0.25) \, (15)}{30} = 1,250,000$ cubic feet per day.

The amount of water to be pumped w s also calculated by a method based on the amount of oxygen available om East River water and the average amount of oxygen consumed by ater in the canal. Although there is no evidence that sewage requires oxygen equivalent to its oxygen consumed value to oxidize it under natural conditions, this calculation is interesting in that the two methods of calculation used gave practically the same result. For this reason the writer thought this calculation from chemical data might be of general interest, and has included it in this report.

This calculation was based on the assumption that the volume of the canal water and the amount of oxygen consumed by it bears some relation to the amount of water to be pumped and the free or dissolved oxygen in it. We can express this relation algebraically as

$$xO_d = KSO_c$$

where x = quantity of East River water to be pumped in cubic feet per day.

O_d = amount of dissolved oxygen in parts per million in the water to be pumped.

S = amount of sewage to be oxidized in cubic feet per day.

O_c = oxygen consumed by S in parts per million.

K = ratio of amount of dissolved oxygen in flushing water to amount required to oxidize the organic matter.

If O_d is all to be used up, K becomes unity, and the quantity to be pumped is $x = \frac{SO}{O_d}$.

It appears from analyses made of East River that 7.5 c.c. per liter is a fair average value for O_d.

Weight of liter O = 1.429 grams.
Weight of 1.0 c.c. O = 0.00143 gram.
Weight of 7.5 c.c. O = 0.0107 gram.

Therefore $O_d = 10.7$ parts per million and $x = \frac{SO}{10.7}$.

We will compute first the amount of water needed to render innocuous the sewage discharged into the canal. The total sewage discharged into the canal was estimated at 793,000 cubic feet per day. $O_c = 165$ parts per million. Therefore $x = \frac{793{,}000 \times 165}{10.7} = 12{,}200{,}000$ cubic feet per day.

If we allow a factor of safety of 2 to cover future increase of sewage flow, x would equal 12,200,000 × 2 = 24,400,000 cubic feet per day.

The amount of water needed for flushing the canal, supposing no more sewage is allowed to enter and thirty days are allowed for flushing, was computed as follows. The volume of the canal water is 10,000,000 cubic feet. S in our formula would then be $\frac{10{,}000{,}000}{30} = 333{,}330$ cubic feet per day. The average value for O_c is 46.1. Then

$$x = \frac{333{,}330 \times 46.1}{10.7} = 1{,}440{,}000 \text{ cubic feet per day.}$$

Summing up these calculations, it appears that if sewage is allowed to continue discharging into the canal perhaps 25,000,000 cubic feet of water will have to be pumped daily to dilute the canal water sufficiently to render it innocuous. If the district is to be sewered, 1,500,000 cubic feet per day will be necessary.

SUMMARY AND CONCLUSIONS

The Gowanus Canal in its present condition is unsanitary and a nuisance. Sewage enters the canal and stays there. The heavier particles settle out at once, forming banks in front of the outlets of the sewers. The light, flocculent matter moves up and down with the tide and is gradually deposited, silting up all portions of the canal

The water levoid of oxygen, this sludge then undergoes putrefaction. Inasmucn as the temperature of 65° to 70° F. is sufficient cause the sludge to give off putrid gases and the average tempera- of the canal even in the winter time is about 70° F., it is easily why the nuisance exists all the year round.

n proceeding to summarize the results from the special point of of this investigation, an attempt will be made to answer the estions raised in the first portion of this part of this report.

The odors of the factories are distinct from those of the canal and are not offensive. The bad smells are due to the putrefaction of nitrogenous matter in the sewage and sludge.

The water which now fills the is a mixture of sewage, terrestrial, and harbor water. At the of the canal the water is 0.65 sewage, 0.34 terrestrial water, and 0.0 harbor water. At Hamilton Avenue it is 0.10 sewage, 0.20 terrest water, and 0.70 harbor water. The average sewage density of the whole canal is 0.25. Brooklyn sewage is much stronger than Massachusetts sewages. The water at the head of the canal is slightly stronger han Andover sewage, and the average value of the whole canal corres nds very nicely to Lawrence sewage.

The amount of organic matter present is very large, and to destroy it would require an amount of oxygen equivalent to that contained in

$$\frac{10{,}000{,}000 \times 0.25 \times 165}{10} = \text{say to } 45{,}000{,}000 \text{ cubic feet of harbor}$$

water, which is about 75 per cent. saturated. The amount of putrescible substances present is large, and their oxidation is probably inhibited by antiseptic wastes contributed by the Bond Street sewer. The storm sewers bring down much matter which is indifferent to chemical change and which, silting up the canal, makes constant dredging necessary. The average of analyses on the sludge shows the amount of this to be about twice that of the organic matter present.

The pollution due to the factories is largely vegetable carbonaceous and nitrogenous organic matter. The Tartar Chemical Company and the starch factory contribute most of this. The amount of this waste, however, is small when compared to that contributed by the city sewers.

The canal water is about fifty times as much polluted as that in the part of the harbor adjoining its outlet; the ebb and flow of the tide do comparatively little toward renewing the water in the canal, the water in the latter practically simply surging back and forth.

The water required for pumping after dredging has taken place depends upon the method used. The amount required to render innocuous the sewage which is discharged into the canal and to provide for future increase is perhaps 25,000,000 cubic feet per day. To flush out the present contents in thirty days 1,500,000 cubic feet of East River water would be required daily. Therefore if flushing alone were resorted to 25,000,000 cubic feet per day are necessary. If the district is first sewered and the canal then flushed 1,500,000 cubic feet would be required daily.

G. 9/.
1 Diag.
1 Plate
2 Pla

25 1911

not acc'd
F.J.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

W YORK
LIBRARY
LENOX AND
FOUNDATIONS

CONTRIBUTIONS

FROM THE

SANITARY RESEARCH LABORATORY

AND

SEWAGE EXPERIMENT STATION

VOLUME VI

REPRINTED PAPERS
PRICE $1.00

BOSTON, MASSACHUSETTS
1910

VII

. MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# CONTRIBUTIONS
FROM THE
SANITARY RESEARCH LABORATORY
AND
SEWAGE EXPERIMENT STATION

VOLUME VI

REPRINTED PAPERS
PRICE $1.00

BOSTON, MASSACHUSETTS
1910

TABLE OF CONTENTS

1. Introduction. W. T. Sedgwick, Director.

2. On the Mills-Reincke Phenomenon and Hazen's Theorem Concerning the Decrease in Mortality from Diseases Other than Typhoid Fever Following the Purification of Polluted Water Supplies.
   William T. Sedgwick and J. Scott MacNutt. (Jour. Inf. Dis., Vol. VII, 1910, pp. 489-564.)

3. The Foundations of Prevention.
   William T. Sedgwick (Trans. First Conference on Prevention of Infant Mortality, New Haven, Conn. 1910).

4. A Comparative Study of Intestinal Streptococci from the Horse, the Cow, and Man.
   C.-E. A. Winslow and G. T. Palmer (Jour. Infectious Diseases, Vol. VII, No. 1, (1910), pp. 1-16).

5. An Investigation of the Extent of the Bacterial Pollution of the Atmosphere by Mouth Spray.
   C.-E. A. Winslow and E. A. Robinson (Jour. Infectious Diseases, Vol. VII, (1910) pp. 17-37).

6. The Disinfection of Water and Sewage.
   Earle B. Phelps (Proc. Eng'r's Club of Phila., Vol. XXVII, No. 21, 1910).

7. Disinfection of Sewage and Sewage Effluents.
   Earle B. Phelps (Trans. Am. Soc. Munic. Improvements, 1910).

8. Water Pollution and Water Purification at Jersey City, N. J.
   C.-E. A. Winslow (Jour. Western Soc. Eng., Vol. XV, 1910).

9. The Field for Water Disinfection from a Sanitary Standpoint.
   C.-E. A. Winslow (Proc. Second Ann. Meeting Illinois Water Supply Assn. 1910).

INTRODUCTION

By W. T. SEDGWICK, Director.

Sanitary Research Laboratory and Sewage Experiment
Station, Massachusetts Institute of Technology,
Boston.

The present volume is the sixth in the series of reprints of essentially similar character,—namely of researches and addresses touching various aspects of Sanitary Science and the Public Health,— as these subjects have been treated during the last year or two by those connected with the Sanitary Research Laboratory and Sewage Experiment Station of a great American School of Science and Technology. Like the volumes of the same series which have preceded it, this one also owes its existence to the unflagging interest and unstinted co-operation of an anonymous friend of the Institute who, "feeling keenly the incongruity of a twentieth century civilization which, rightly enough, boasts of its achievements in mechanical, industrial and other sciences, yet regards human life so carelessly as to go on polluting rivers and harbors with vast and ever increasing streams of putrefying sewage," is determined to do whatever can be done to bring about a change for the better. Our first and most agreeable duty is to return thanks, as we hereby do, to this Donor, not only for continued financial support but also for friendly criticism and unfailing inspiration.

From the very beginning of our work Professor Charles-Edward Amory Winslow has occupied the responsible and often trying position of Biologist-in-Charge of it. This responsibility he has now laid down for another and larger field of labor. A review of the entire series of reprinted papers now comprising six volumes will prove perhaps better than anything else the extent of his influence and the scope of his researches. The larger part of whatever influence and success have been achieved by our Sanitary Research Laboratory and Sewage Experiment Station belongs to Professor Winslow; and to him the thanks not only of the Director but of all who have been associated with him in a work which he has so successfully prosecuted are hereby gratefully tendered.

Professor E. B. Phelps continues to occupy with us the same important position as heretofore, namely, that of Research Chemist and Bacteriologist, and the Staff of the Laboratory and Station have been strengthened by the addition as Research Associate of Mr. George T. Palmer, upon whom much of the responsibility for the actual conduct of our investigations now falls; of Professor S. C. Prescott, to whom we are glad to be at liberty to turn for advice and suggestions; and of Mr. Selskar M. Gunn, recently appointed Instructor in Sanitary Biology at the Institute after an extensive experience as Assistant Bacteriologist to the State Board of Health of Iowa, and, later, Health Officer of the City of Orange, N. J.

Until very recently the problems connected with the sanitary disposal of ordinary city sewage have been deemed of so much importance that the principal energy and resources of our Experiment Station have been concentrated upon these. And even yet we cannot say that all or even the most important of these problems have been satisfactorily solved. At the same time there is today a widespread agreement among experts as to the general methods which should be employed in the disposal of the city sewage. It is now well recognized, for example, that there is no one solution of this vast and varied problem. In any particular case much depends upon the location, climate, soil, and other intrinsic or environmental conditions. Sometimes disposal by simple dilution in sea-water suffices. Sometimes this is highly objectionable. If dry and sandy soil abounds in close proximity to a particular city, then disposal by intermittent filtration may be the best solution of the problem. If on the other hand, the sewage of a manufacturing city is strongly acid, sand filtration without special preparatory treatment of the sewage, depending as it does upon bacterial activity, may be quite out of the question. If the city to be drained is situated upon a lake from which drinking water must be drawn, a difficult problem arises, since disposal in lakes, even at a great distance from the intake of waterworks, may prejudice the purity of public water supplies.

No better evidence of the many sidedness of the sewage problem or of the variety of solutions applicable to its various phases is needed than can be found in the timely and valuable treatise on "Sewage Disposal" which has lately issued from the press under the authorship of three graduates of the Institute of Technology, namely, Professor Leonard P. Kinnicutt, Head of the Chemical Department of the Worcester (Mass.) Polytechnic Institute, Professor C.-E. A. Winslow, Assistant Professor of Sanitary Biology and Biologist-in-Charge of the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology, (from which the present volume of Contributions and those that have preceded it have come) and Mr. R. W. Pratt, Chief Engineer of the State Board of Health of Ohio. Those who would appreciate the magnitude, the variety and the difficulty of the sewage disposal problem in the United States would do well to consult this important volume, no small part of which has been the outgrowth of the series of researches recorded in the several volumes of the present series of "Contributions."

It has been the often repeated wish of the Donor from the outset that our Laboratory and Station should not only make original contributions to the solution of the difficult problems of sewage disposal, but should also take an active part in the education of the public along lines of cleanliness, sanitation, public health, and more wholesome living. It is interesting to note accordingly, that, of the present volume, three of the papers and nearly two-thirds of its pages, represent purely scientific and original work; while the remainder are devoted to public exposition, popular information, or educational aspects of Sanitary and Public Health Science.

Massachusetts Institute of Technology.

Boston, September, 1910.

The

Journal of Infectious Diseases

FOUNDED BY THE MEMORIAL INSTITUTE FOR INFECTIOUS DISEASES

VOL. 7 *August 24, 1910* No. 4

ON THE MILLS-REINCKE PHENOMENON AND HAZEN'S THEOREM CONCERNING THE DECREASE IN MORTALITY FROM DISEASES OTHER THAN TYPHOID FEVER FOLLOWING THE PURIFICATION OF PUBLIC WATER-SUPPLIES.*

W. T. SEDGWICK, PH.D., Sc.D.
Professor of Biology at the Massachusetts Institute of Technology, Boston,
AND
J. SCOTT MACNUTT, A.B., S.B.
Health Officer of Orange, New Jersey

TABLE OF CONTENTS.

PAGE
I. Introduction 490
II. The Mills-Reincke Phenomenon 491
III. Dr. Reincke's Observations on the Relation of Total Death-Rate to Water-Supply in Hamburg, Germany, 1894–97 492
IV. Dr. Reincke's Studies on the Relation of Infant Mortality to Water-Supply in Hamburg and Altona, 1893–97 494
V. Further Discussion of the Influence of Water-Supply upon Death-Rates in "Die Gesundheitsverhältnisse Hamburgs im neunzehnten Jahrhundert" (1901) 499
VI. Mr. Mills's Further Studies on the Water-Supply and Total Death-Rate, etc., of Lawrence, Massachusetts, and His Address to the City Government of Lawrence, 1893–1902 505
VII. Discussion by Mr. Allen Hazen, C.E., of the Water-Supply of Lawrence in Relation to the Total Death-Rate, 1901 506
VIII. A Graphical Demonstration of the Lawrence Phenomena Published by Mr. Mills, 1904 507

---

* Received for publication April 27, 1910.

IX. Formulation of Hazen's Theorem, 1904 507
X. Other Data and Discussions Bearing on the General Subject . . 511
XI. A Recapitulation of the Literature, and a Brief Outline of the Work of the Authors 512
XII. A Graphical Demonstration and Discussion, by the Authors, of the Hamburg Phenomena 513
XIII. Graphical Demonstration and Discussion of the Lawrence Phenomena 521
XIV. Graphical Demonstration and Discussion of the Lowell Phenomena . 526
XV. A Graphical Demonstration of the Phenomena at Manchester, New Hampshire, a City Having a Water-Supply of Good Quality . . 530
XVI. A Comparative Study of the Data Derived from Lawrence, Lowell, and Manchester 535
XVII. Studies of Similar Phenomena in Some Other American Cities . 544
XVIII. Fluctuations of Population in Periods of Panic and Prosperity as Sources of Statistical Error 554
XIX. Summary and Conclusions 561

I. INTRODUCTION.

It is nowadays commonly understood that the purification of a polluted water-supply produces a marked decrease in the mortality from typhoid fever among persons using the water for drinking and other domestic purposes, but it is not as yet generally recognized that such purification produces also a marked decrease in deaths from other diseases.

In 1893–94 it was observed, independently, by Messrs. Hiram F. Mills, C.E., of Lawrence, Massachusetts, and Dr. J. J. Reincke, of Hamburg, Germany, that the purification of the polluted public water-supplies of Lawrence and of Hamburg, respectively, was producing a notable decline in the general death-rate of each of these cities. The attention of Mr. Allen Hazen was about the same time turned to the subject, and some years later, in a paper presented to the International Engineering Congress held at the St. Louis Exposition in 1904, he drew from an examination of the death-rates of certain cities which had radically improved polluted water-supplies the following conclusion:

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.

This novel statement has not hitherto received the attention which it deserves, and in view of this fact, as well as in order to test the range and accuracy of Mr. Hazen's conclusion, and also if possible to find an explanation for it, we have undertaken a careful examination of the vital statistics of a number of cities each of which has changed more or less suddenly from a polluted to a purified water-supply.

On August 14, 1908, we published in "Science" a preliminary communication announcing in part the results of our study and confirming Mr. Hazen's statement. We also contributed to the volume on "Tuberculosis in Massachusetts," prepared by the Massachusetts State Committee for the International Congress on Tuberculosis held in Washington, D.C., September 21 to October 12, 1908, and published in Boston in 1908, a paper entitled "On an Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis."

As will appear beyond, circumstances arose not long after the publication of our preliminary communication which made it seem desirable to repeat some portions of our work, and especially to take into consideration questions relating to the constancy of increase of population ordinarily estimated for American cities between census years. Some delay has thus been caused, but we now present the complete paper, which we venture to believe has meanwhile gained both in scope and in trustworthiness.

II THE MILLS-REINCKE PHENOMENON.

Shortly after the introduction of a filtered and purified water-supply into Lawrence, Massachusetts, in September, 1893, it was observed by Mr. Hiram F. Mills, C.E., a member of the State Board of Health of Massachusetts, then a resident of the city of Lawrence and chief engineer of the company controlling the water power of that city, that a marked decrease in the general death-rate of the city, and not merely in the death-rate from typhoid fever, was taking place. A few months earlier (May, 1893) filtration of the public water-supply had likewise been established for the city of Hamburg, Germany, and there also it was observed by Dr. J. J. Reincke, health officer of that city, that the general death-rate was declining more rapidly than could possibly be accounted for by the deaths from typhoid fever alone. To this important discovery, made thus indeendently by Mr. Mills in Lawrence and Dr. Reincke in Hamburg, we have, because of its fundamental and far-reaching significance, plied the name of *The Mills-Reincke Phenomenon.*

Mr. Allen Hazen, the now well-known civil and sanitary engineer, who had long been more or less closely associated with Mr. Mills, visited Europe early in 1894, and while in Hamburg conferred with r. Reincke. He was impressed with the favorable results of filtration as observed and described by Dr. Reincke, and on his return to America he mentioned Dr. Reincke's observations to one of the writers (W. T. S.). He also stated in the first edition (1895) of his "Filtration of Public Water-Supplies" (p. 177):

> The death-rate [of Hamburg] since the introduction of filtered water has been lower than ever before in the history of the city, but as it is thought that other conditions may help to this result no conclusions are as yet drawn.

To this statement he appended in a later edition a table showing the deaths in Hamburg from typhoid fever and from all causes 1880–98, i.e., before and after the introduction of filtration.

III. DR. REINCKE'S OBSERVATIONS ON THE RELATION OF TOTAL DEATH-RATE TO WATER-SUPPLY IN HAMBURG, GERMANY, 1894–97.

The Hamburg filters began their work in May, 1893, and for that year the total death-rate showed an extraordinary decrease from that of preceding years, and a greater decrease than could be accounted for by the drop in the typhoid fever death-rate alone. Dr. Reincke's observations concerning this remarkable phenomenon were published from time to time in his Annual Reports[1] and may be quoted (in literal translation) or summarized as follows:

> In the year 1893 . . . . the total death-rate of Hamburg was 20.4 per thousand living. The mortality has never been so low before . . . . since the beginning of vital statistics in Hamburg in 1820. . . . . Manifestly the chief explanation of this favorable result is that the cholera of 1892 carried off an extraordinarily large number of people, especially of the weaker and less resistant, a part of whom would otherwise not have died until 1893. Whether the great improvement of the water has been of influence can be ascertained only after several years. The figures given in connection with infant mortality speak, however, strongly for this theory (Report for 1893, p. 15).

---

[1] *Berichte des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates.*

For 1894 Dr. Reincke found the total death-rate to be 17.9 per thousand living.

> Thus the mortality has receded still lower even than that of last year, which, as has been said, was the most favorable since the beginning of recorded vital statistics in Hamburg. . . . .
>
> It is not altogether easy to offer a sufficient explanation of this favorable result. That the effect of the cholera of 1892 in carrying off prematurely many weak individuals is still operative, is not very probable, for the favorable conditions of 1894 appear in no age group so strikingly as among infants under one year, all of whom have been born since the epidemic. The death-rate of such infants is 201.9 per thousand [under one year of age] for 1894, as compared with a fifteen-year average of 287.1.
>
> On the other hand, there is greater reason than in the preceding year for attributing a considerable share in the altered conditions to the improved water-supply, and the results for 1892 and 1893 of the influence of the water on the mortality of children from diarrhea and gastro-intestinal diseases are freshly confirmed (Report for 1894, pp. 11, 13).

In 1895 the total death-rate was 18.9 per thousand living, i.e., 1.0 more than in 1894.

> Nevertheless the mortality was still more favorable by 2.7 per thousand than in 1890, the most favorable year before the introduction of filtration, and more favorable by 5.8 than the mean of the ten years before the cholera epidemic, i.e., 1882–91 (Report for 1895, p. 11).

For 1896 the total death-rate is reckoned at 17.1 per thousand living, the lowest ever observed in Hamburg up to that time.

> Undoubtedly, the especially favorable result for this year is to be attributed chiefly to the cool wet weather from the middle of June to the middle of July, on account of which the high infant mortality of the summer was speedily cut down. . . . . That the year has passed as favorably as the three preceding years is fresh confirmation of the fact that *since the filtration of the drinking water the health conditions in Hamburg have improved in a quite extraordinary manner.* (Ist eine neue Bestätigung dafür, dass seit der Filtration des Trinkwassers sich die Gesundheitsverhältnisse Hamburgs in ganz ausserordentlicher Weise verbessert haben.) (Report for 1896, p. 11, italics ours.)

For 1897 the total death-rate of Hamburg "Stadt" (exclusive of the suburbs) is reckoned as 17.0 per thousand living. Again no rate so low had ever before been observed in the history of the city (Report for 1897, p. 12).

All the more weight must be given to the statistical statements made above because these were based upon an annual official enumeration of the population.

IV. DR. REINCKE'S STUDIES ON THE RELATION OF INFANT MORTALITY TO WATER-SUPPLY IN HAMBURG AND ALTONA, 1893-97.

In Dr. Reincke's Annual Report for 1892[1] we find a searching examination of the effect of water-supply upon infant mortality (particularly as due to gastro-intestinal diseases), which, because of its early date and its obvious importance for all students of the relations of polluted water to public health science, we shall either quote in careful translation or summarize, as follows:

> It is usually assumed that the greater part of the deaths from gastro-intestinal diseases (*Brechdurchfall*)[2] in summer is to be explained by the high summer temperature, particularly through the action of warmth on the principal food of infants, i.e. milk. Our local observations, however, indicate that the matter is somewhat more complicated than this (p. 10).

Tables and diagrams are given of deaths from diarrhea and gastro-intestinal diseases, by months, for Hamburg and for Altona, with the mean monthly temperatures, 1871-92. In connection with these it is pointed out that the parallelism between deaths and high temperatures is not well marked, but that, on the contrary, there have been distinct outbreaks of these diseases during cold-weather periods. Also, that the curves for winter deaths of infants under one year from gastro-intestinal diseases are not parallel in Hamburg and Altona, as is the case with those of the summer period Reincke was unable to discover similar winter outbreaks in any other German city except, for certain years, in Berlin. We quote further and at length:

> In Bockendahl's "Generalbericht über das öffentliche Gesundheitswesen der Provinz Schleswig-Holstein für das Jahr 1870," p. 10, we read: "Still more striking was an epidemic of gastro-intestinal diseases in Altona in January which proved fatal to 43 children. As the cases were observed in all parts of the city and the medical officer was unable to explain the phenomenon, he procured from the Gas and Water Company a statement regarding any interruptions in the supply of pure water to the city during the year 1870. He then learned that the city was supplied during a few days in January with unpurified Elbe River water. However little reason there may

---

[1] *Bericht des Medizinal-Inspektorats über die medizinische Statistik des Hamburgischen Staates für 1892*, published without date, but presumably late in 1893.

[2] We have not been able to find any exact English equivalent for the term *Brechdurchfall*, which denotes literally a condition characterized by diarrhea and vomiting. Mr. Hazen's rendition "cholera infantum," employed in his translations from Dr. Reincke in Appendix II of his "Filtration of Public Water-Supplies," does not appear to be allowable. *Brechdurchfall* is applied to both adults and children, but more frequently to the latter because gastro-intestinal disturbances are much more common during the early years of life. Throughout our translations of, and references to, the writings of Dr. Reincke and his associates, we shall render the term, with an approximation to accuracy, sometimes as "gastro-intestinal disorders," and sometimes, especially when it is applied to fatal cases, as "gastro-intestinal diseases," without, however, necessarily implying by the latter phrase the existence of discoverable lesions.

be for regarding the connection between these two circumstances as proved, it is only proper that at all times interruptions in the pure water service be closely watched, because only in this way can reliable conclusions be reached and dangers be avoided. . . . . "

Dr. Kraus, who was at that time the medical officer of Altona, and who made the studies upon which Bockendahl's statement is based, subsequently became health officer of Hamburg; and, in a more lengthy opinion . . . . dated 1874, earnestly advocating the establishment of sand filtration in Hamburg, supported his position with the above observations, although with the caution that they are not to be regarded as entirely conclusive. In his annual report on the vital statistics of Hamburg for 1875 he suggests (p. 17) that the addition of unfiltered Elbe water to milk had probably been connected with the infant mortality of Hamburg, which mortality was very high in comparison with that of London (dass der Zusatz von unfiltrirtem Elbewasser zu der Milch wahrscheinlich an der im Vergleich zu London sehr hohen Sauglingssterblichkeit Hamburgs betheiligt sei.) He later repeated this opinion both in oral and in written statements.

Meantime so much material for observation has accumulated that his view may now fairly be regarded as proved. . . . .

Years ago, on observing the epidemic behavior of typhoid fever, in Altona . . . . I suggested that at the Altona waterworks disturbances in the action of the filters occurred in connection with frost, causing the distribution of water insufficiently purified. Wallichs of Altona, on the ground of further observations on typhoid fever, has come to the same conclusion, and lately Robert Koch, on the occasion of the small winter epidemic of Asiatic cholera in Altona, has proved that our hypothesis is correct. When open filters are cleaned in cold weather, it is a matter of common observation that the germs in the water are not sufficiently held back by the filters; and, as an actual fact, simultaneously with these disturbances of filtration there have occurred not only the explosive typhoid outbreaks of 1886, 1887, 1888, 1891, and 1892, and the Asiatic cholera outbreaks of 1871 and 1893, but also the increases of gastro-intestinal disorders in Altona. It can, therefore, no longer be doubted that these phenomena stand in the relation of cause and effect. It is thus explained also why in warm winters, as above mentioned, there have been no such outbreaks, and why gastro-intestinal disorders in winter have not been parallel in Hamburg and Altona.

In Hamburg the winter increases [of gastro-intestinal disorders] cannot be explained so simply. It seems probable, rather, that northeast storms, through the high tides which they cause, bring polluted water in greater quantity to the intake of the waterworks. It cannot be demonstrated that every such occurrence has caused an increase in infant mortality, but in many instances a noteworthy coincidence occurs. . . . . This point could be decided only by careful bacteriological determinations, and we have some such evidence for the last months of the year 1892, when daily bacteriological examinations of the city water were made at the Hygienic Institute, altho examinations of the river water itself were not begun until later. It was thus found that the bacterial content of the water varied between 200 and 600 at the end of October and the beginning of November; that it rose after November 19 to about 3,000; after December 4, to 4,000–5,000; and on December 18, to 7,500; and finally dropped rapidly in January to 200–500. On December 4 there occurred a storm-tide 4.6 m. in height, following a series of moderate high tides, and the December increase in infant mortality corresponded with the increase in bacteria in the water-supply mentioned above.

[TABLE 1.]

Stralau Waterworks, Bacteria per c.c.		Deaths from Acute Intestinal Diseases		
		Total	Gastro-intestinal Diseases	
			At All Ages	Infants under One Year of Age
1886				
March 23 145	March 21–27	...	4	4
March 30 2,300	March 28–April 3	34	20	18
April 6 500	April 4–10	106	49	46
April 13 125	April 11–17	99	46	44
April 20 360	April 18–24	56	25	25
April 27 105	April 25–May 1	46	22	22
1888				
March 1 16	March 11–17	24	4	4
March 15 3,600	March 18–24	76	29	29
	March 25–31	73	25	23
April 3 440	April 1–7	47	17	17
	April 8–14	47	21	21
April 16 125	April 15–21	50	20	18
	April 22–28	27	15	15
	April 29–May 5	28	12	12
1889				
January 16 112	January 13–19	28	4	4
	January 20–26	35	9	8
February 1 1,730	January 27–February 2	38	12	12
	February 3–9	65	17	17
February 15 1,600	February 10–16	86	22	22
	February 17–23	59	13	13
	February 24–March 2	35	8	8
March 4 2,400	March 3–9	47	13	12
	March 10–16	54	22	22
March 18 4,800	March 17–23	112	53	52
	March 24–30	215	118	116
April 1 264	March 31–April 6	120	61	60
	April 7–13	82	40	38
April 15 98	April 14–20	44	18	14
1891				
December 15, 1890 .. 123	December 21–27, 1890	22	6	6
January 2, 1891 450	December 28, 1890–January 3, 1891	31	4	4
	January 4–10	25	3	3
January 15 1,325	January 11–17	25	6	6
	January 18–24	18	2	2
	January 25–31	36	7	7
February 1 13,000	February 1–7	61	12	12
	February 8–14	158	61	61
February 16 4,000	February 15–21	160	50	50
	February 22–28	104	42	41
March 3 120	March 1–7	88	29	29
	March 8–14	68	20	20
March 17 310	March 15–21	43	14	14
	March 22–28	38	10	10
April 1 85	March 29–April 4	28	9	9
	April 5–11	41	9	9
April 15 800	April 12–18	39	13	13
	April 19–25	46	16	16
May 1 140	April 26–May 2	25	11	11
	May 3–9	49	19	18
1893				
?	February 5–11	23	4	9
?	February 12–18	56	20	19
?	February 19–25	110	41	41
?	February 26–March 4	110	40	39
?	March 5–11	69	20	19
?	March 12–18	39	10	9

A further support for this theory is found in the conditions at Berlin, where, likewise, frost has repeatedly interfered with filtration. The above table gives

> the deaths from acute intestinal diseases, for several winter periods in which striking increases in mortalities in these diseases have appeared. It is obvious that, of the deaths enumerated in the first column, a predominant number is among little children. For comparison the bacteriological examinations are given, according to Plagge and Proskauer, of the tap water from the Stralau waterworks. Unfortunately the figures for 1892 are wanting.
>
> No one can doubt, after this demonstration, that here also the delivery of insufficiently purified water every time cost the lives of many children. Still more striking is the evidence, from the publications of the Statistical Office at Berlin, that other parts of the city, supplied with better water from the Tegel works, completely escaped these increases in mortality, precisely as was the case in the well-known typhoid epidemic of February and March, 1889.
>
> . . . . The fatal effects of the water are not confined, however, to those infants dying from well-defined intestinal diseases, for there is a large number besides who must have fallen victims with less striking intestinal symptoms. It appears, furthermore, that almost the only children affected were those not nursed by their mothers or by wet-nurses but fed on the milk of animals or other substitutes, which were mixt with more or less water.
>
> So much for the winter conditions. As for the summer, the work of Plagge and Proskauer shows that the filters have then also occasionally delivered bad water. What influence this may have had is difficult to determine, since at that season gastro-intestinal disorders show ordinarily a high prevalence. But doubtless the influences of weather and water go hand in hand. This hypothesis is still more probable for Hamburg, because there, with the river water diminished during the summer months, the tides easily run up the river [carrying sewage to the intake] even without the aid of storms. This hypothesis is supported by the extraordinary prevalence of gastro-intestinal disorders in the unusually dry warm years of 1886, 1887, and 1892. If this be the case, when the intake is moved higher upstream and sand filtration is started, we may expect a substantial decrease of infant mortality. Not only should the winter increases entirely disappear, but those of the summer ought to be notably diminished. [How well this prophecy was borne out is shown by the table given on p. 121 of the "Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert" published some years later, in 1901.] Moreover, it is not the infants only who will be benefited, for, as the Berlin figures show, there are also many cases of gastro-intestinal disorders among children from one to five years of age, and even adults do not entirely escape (pp. 13–17).

We may mention parenthetically that many of the valuable observations just quoted have been presented in English by Mr. Hazen in the first (1895) and subsequent editions of his "Filtration of Public Water-Supplies," Appendix 11.

Dr. Reincke's report[1] for the following year (1893) gives the mortality under one year of age, reckoned per thousand living in that age-group, for 1893 and earlier years, as follows (p. 17): 1885, 277.2; 1886, 368.8; 1887, 347.5; 1888, 289.8; 1889, 316.5; 1890, 276.3; 1891, 288.7; 1892, 404.8; 1893, **240.2**.

---

[1] For full title of reports see footnote, p. 492.

How uneven is the distribution by age months of this mortality of infants under one year of age, is shown by the following table.

Economy of space forbids our reproducing in full the table (p. 40) referred to, but we present a summary of it (Table 2).

TABLE 2.

AGES OF INFANTS DYING UNDER ONE YEAR, BY MONTHS.

	Average 1884–92 Inclusive Percentage	1893 Percentage		Average 1884–92 Inclusive Percentage	1893 Percentage
In the 1st month	24.2	27.0	In the 7th month	5.6	5.7
" " 2d "	12.9	14.3	" " 8th "	5.2	4.5
" " 3d "	11.0	11.9	" " 9th "	4.8	4.2
" " 4th "	9.1	9.6	" " 10th "	4.5	3.8
" " 5th "	7.8	7.2	" " 11th "	4.2	3.0
" " 6th "	6.5	5.9	" " 12th "	4.0	2.9
				100	100

Under "diarrhea and gastro-intestinal diseases" (Durchfall und Brechdurchfall), the following figures are given for the deaths of infants under one year of age for these causes by years:

1884.............	1,143	1889.............	1,557
1885.............	1,189	1890.............	1,198
1886.............	1,601	1891.............	1,500
1887.............	1,758	1892.............	2,541
1888.............	1,063	1893.............	857

Since I expressed myself in detail on these causes of infant mortality in my report for 1892 [already quoted above], it suffices for the present year [1893] to call attention to the highly significant decline in the number of these deaths and to the fact that this year the increase in mortality in December, often previously observed, is entirely absent. From the thorough studies recorded in last year's report it is highly probable that this favorable result is to be attributed largely to the filtration of the public water-supply, altho this point can be positively decided only after the experience of future years. Especially noteworthy is the considerable increase of deaths from these diseases in the second half of September, following a temporary pollution of the water which led at the same time to an outbreak of Asiatic cholera (pp. 43–44).

Three years later Dr. Reincke repeats a portion of the above table, adding to it the deaths from diarrhea and gastro-intestinal diseases for 1894, 1895, and 1896, which were 708, 918, and 767, respectively (see our Chart 1). He may well have remarked, in view of these figures together with the increasing population:

In no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these (Report for 1896, p. 46).

V. FURTHER DISCUSSION OF THE INFLUENCE OF WATER-SUPPLY UPON DEATH-RATES IN "DIE GESUNDHEITSVERHÄLTNISSE HAMBURGS IM NEUNZEHNTEN JAHRHUNDERT" (1901).

In 1901 there appeared a comprehensive treatise on the "Sanitary History of Hamburg in the Nineteenth Century," prepared under the editorship of Dr. Reincke.[1] In this work the declines in the total death-rate and in the death-rates from various diseases following the introduction of filtration into Hamburg are still further considered, and additional evidence is given for the existence of a relation between water-supply and gastro-intestinal diseases (particularly of infants). The observations on these points we have abstracted, mainly in literal translations and at some length, as follows:

1. General Death-Rate.

In the century curve of the general death-rate . . . . four peaks of specially high mortality stand out predominantly; these are the cholera years 1831 and 1832, 1848, and 1892 and the small-pox year 1871. Between them lies a greater number of lesser elevations, which are likewise to be attributed to greater or smaller epidemics of infectious diseases. . . . . Following each of these peaks there sets in regularly a compensatory decline in mortality.

Entirely different from these declines is that which set in after the cholera epidemic of 1892; for not only was this deeper than any other before it, but it has also lasted now throughout eight years—the beneficent result of the filtration of the water-supply which has been in operation since 1893 and to which we shall repeatedly return in connection with our consideration of the mortality from particular diseases (p. 90).

Comparing the twenty-five years 1872–1896 with the following four years, the average annual mortality has dropped from 25.0 to 17.2, a decrease of 7.8 per 1,000. In this improvement at least 6.1 per 1,000 may be regarded as due to general measures of sanitation, and of this again 3.0 at the very least as due to the betterment of the water by filtration. In this there have been reckoned for the infants under one year only 1.8 instead of 2.7, to avoid by any chance putting the figure too high; for cholera 0.8, and for typhoid fever 0.4 per 1,000. Even leaving the cholera out of account, an average improvement by at least 2.2 per 1,000 must be acknowledged. That gives, even with this thoroughly cautious and conservative calculation, for a population of, in round numbers, 340,000 (as the number stood in 1872), an annual number of deaths 748 fewer, and for the present population of 700,000, 1,540 deaths fewer in a

---

[1] *Die Gesundheitsverhältnisse Hamburgs im neunzehnten Jahrhundert*, den ärztlichen Theilnehmern der 73. Versammlung deutscher Naturforscher und Aerzte gewidmet von dem Medicinal-Collegium, Hamburg (Verlag von Leopold Voss), 1901. Translating freely, we shall apply to this work the English title given above—the term "history" being suggested by Dr. Reincke's preface. As the sections from which we quote bear no signatures, we assume that these sections are editorial and hence to be credited—at least in the main—to Dr. Reincke; many of the statements which we have quoted from his Annual Reports are, in fact, either paraphrased or amplified in the later work. In making this assumption we hope that we do no injustice to any of Dr. Reincke's collaborators.

> year, which are to be accredited to the filtration of the drinking water. Undoubtedly, however, the real figures are much higher.
>
> Through the improvement of the water-supply already discussed and the other contemporaneous measures of sanitation, Hamburg has caught up with most of the larger German cities, which hitherto had had more favorable sanitary conditions, and has surpassed many (pp. 310, 312).

2. Infant Mortality, Diarrhea, and Gastro-intestinal Diseases.

The term "Infant Mortality," as we shall use it here, has a special significance corresponding to the German "Saüglingssterblichkeit, d.i. der Sterblichkeit der im ersten Lebensjahre stehenden Personen," i.e., the mortality of infants under one year of age. As 90 per cent of all deaths from diarrhea and gastro-intestinal diseases (Durchfall und Brechdurchfall) in Hamburg in the nineteenth century occurred among infants under one year of age, we combine these heads as above.

> It is certainly in consequence of sanitary improvements that, in spite of the growing factory-working population of the city, the *infant mortality has declined so extraordinarily since 1893.* And as a discussion, beyond, on gastro-intestinal diseases will show, *this abrupt and lasting improvement is to be attributed solely to the filtration of the drinking water* (Diese plötzliche und andauernde Verbesserung ist allein der Filtration des Trinkwassers zu danken) (p. 145, italics ours).

Under diarrhea and gastro-intestinal diseases it is noted that the mortality under this title is not statistically complete, since most of the deaths of infants from atrophy and debility (Atrophie und Lebensschwäche) really belong here. The evidence for this is found in their parallelism in seasonal and yearly prevalence.

> Manifestly the as yet unidentified germs of these diseases are ingested by infants with their nourishment—never, however, in mother's milk, but only in artificial substitutes, especially cow's milk—which in some way or other has been contaminated with pathogenic germs. . . . . Among the dangerous contaminations of milk, a great part was played in Hamburg, until 1893, by the unpurified Elbe water, which was introduced into all the dwellings by the city water system. . . . . But since the water has been filtered, a gratifying decline in infant mortality has set in [see our Chart 3] (pp. 149, 150).
>
> Since diarrhea and gastro-intestinal diseases attack chiefly infants under one year [who contributed 90 per cent of the deaths from these causes in Hamburg in the nineteenth century], and as no other diseases of infants claim nearly as many victims, it is evident why the century curve for these causes of death shows an extraordinary similarity to the curve of total infant mortality. Divergences occur only in exceptional years when for a time infants died in increased numbers from other diseases, or adults from diarrhea (p. 207).

The data given below concerning the connection of disease with drinking water suggest, moreover, the question whether the rise of the century curve since the '60's does not stand in a definite connection with the extension of the public water-supply of unfiltered Elbe water. The mean curve by months agrees, as would be expected, almost completely with the curve of deaths of infants from gastro-intestinal diseases. . . . . It virtually follows the atmospheric temperature, for continuous hot days usually unmistakably increase the number of cases of sickness. This subject, however, still needs for complete clarification much more thorough investigation than it has yet had. It must not be forgotten that hot days in May and June scarcely increase gastro-intestinal disorders. Furthermore, in midsummer the temperature is not the only decisive factor, for atmospheric humidity, the distribution of storms, and other factors which are of influence either upon the dissemination of pathogenic organisms or upon their multiplication in milk and other foods, also co-operate.

To *one* of the factors, which plays a part in the dissemination of the germs, attention has been drawn in Hamburg by the fact that the mean curve by months shows here a second rise, which, tho small, nevertheless reached in certain years (e.g., in January, 1883, 1890, 1892; in February, 1889; and in December, 1885, 1886, 1888, and 1891) a very considerable height. This rise occurred always in the winter, but cannot possibly be explained by colds, by life in small, badly ventilated rooms, by injury of milk consequent on heating, or by damage done by Christmas feasting; for, so far as we have been able to determine, in other places of similar climate, the winter increase in gastro-intestinal disorders does not, under ordinary circumstances, take place. Moreover, the case is very different in Hamburg in the various years. And above all, it has ceased since the city water has been well filtered (Und vor Allem da sie aufgehört hat, seitdem das Wasser der städtischen Wasserleitung gut filtrirt wird).

The suspicion cast upon the unpurified Elbe water by these facts is strengthened by observations in other places. In this connection what happened in the district of the Stralau waterworks at Berlin[1] is of great interest. When the waterworks delivered badly filtered water, the population of the district supplied from Stralau responded at once with an increased mortality of infants from gastro-intestinal diseases, which occurred moreover exclusively among infants artificially nourished. A similar observation was recorded in the report mentioned (p. 13) regarding the Altona[1] waterworks as early as 1870, and it was further stated that every time disturbances took place in the operation of the filters at the Altona works, the prevalence of gastro-intestinal disorders increased in the city. Finally, it was recounted that after several high tides in November and after an especially high "storm-tide" on the 4th of December, 1892, bringing about a heavy pollution of the Elbe water at the waterworks intake (proved bacteriologically), an increased infant mortality occurred in Hamburg. The bacterial content of the Elbe River water rose at this time from 200–300 per c.c. to 7,500. Such observations led of necessity to the conclusion, that in other years also when similar events took place the polluted city water was to blame. As already stated (p. 50) there is a possibility that filth particles and pathogenic germs emptied into the Elbe with sewage are driven occasionally by the tide upstream, both to the old and the new waterworks intakes. When this happened there undoubtedly followed as a rule a pollution of the public water-supply, until this danger was eliminated by the establishment of sand filtration and the regular stoppage of pumping at high tide. This danger

---

[1] For fuller accounts of the phenomena at Berlin and Altona see *Jahresb. über die medizinische Statistik des Hamburgischen Staates für 1892;* translations given above, pp. 494–97.

> was not always of the same magnitude, but varied both according to the amount of fresh water coming down, which made difficult or easy the upstream movement of the tide-wave, and also according to the height of the tide-wave coming in from the sea and influenced by wind and weather (pp. 208-9).

Next follows a description of float experiments, by which it was determined how high the tides would have to be, at various stages of the river, to drive water from the outfall of the main trunk sewer upriver to the old and (since 1893) new waterworks intakes, located 6.3 and 8.5 km. upstream, respectively.

> Of course the summer months, with their lower river levels, are by far the most dangerous; there appear, however, extraordinary differences in individual years. On the one hand, there are wet summers with proportionately high fresh water stages, and, on the other, dry years in which the level of the river sinks very low in the hot season. There are also mild, rainy winters in which the river remains high, as well as those in which the whole river-basin freezes up and all the precipitation remains lying on the ground as snow, so that the flow of the river becomes very scanty. Hence for our purposes the separate years must be closely studied (p. 210).

Then follow tables which lack of space forbids us to reproduce, showing, for the period of 1877-93, the varying stages of the river and the exceptionally high tides, and the time relations of these two sets of phenomena.

> If the data in these tables be now compared with the tabulations of the contemporaneous deaths from gastro-intestinal diseases (p. 220), it appears clear that the dry years, with subnormal river stages in the late summer and fall (1877, 1878, 1883-1887, and 1892) and with numerous unfavorable tides, have been especially characterized by deaths from these diseases; but that in the driest year of all, 1893, the significant rise in deaths which was to be expected did not take place. It must be concluded from this that low river stages and higher prevalence of these diseases are not merely independent parallel consequences of a greater summer heat, for in that case gastro-intestinal disorders would have been worse than ever in 1893; but that since 1893 there has been broken a link in the chain which previously connected summer gastro-intestinal disorders with the low water. And that break has come with the filtration of the drinking water begun in 1893. This is confirmed, moreover, by observations of all subsequent years down to the end of the century, during which the low waters of the autumns of 1895, 1898, and 1900 have had no perceptible influence whatsoever upon gastro-intestinal disorders.
>
> Without doubt, therefore, the summer gastro-intestinal disorders of children have been largely increased by the city water, so long as this was not filtered The process may be pictured as consisting simply in the dissemination of the infective agents in kitchens, on utensils, on bottles, on the hands of mothers and nurses, or in the milk itself, in greater quantities through the water than in other ways. The germs then multiply more or less, according to the cleanliness of the people and the condition of their dwellings and according to the weather, and, in greater or less numbers, are ingested by infants with their food.

> The conditions favoring gastro-intestinal disorders in winter are not so clear, altho these also threw suspicion on the water. It is not difficult, in fact, to discover for those winter seasons in which the deaths from gastro-intestinal diseases rose abnormally, storm-tides upon which the blame could be laid; but in our table are found many high tides which apparently had no effect upon these diseases—in particular, all the storm-tides of the autumn equinox. From these a sceptic could derive justification for disputing altogether the connection between polluted water and gastro-intestinal disorders; he could also adduce the fact that before the sewerage of Hamburg and before the introduction of the public water-supply winter increases in gastro-intestinal diseases had appeared, e.g., in 1838 and 1845; and that even after the establishment of filtration, e.g., in March, 1895, there had been observed once more an increase in deaths from these diseases.
>
> On the other hand, we may reply that the winter rises in the '30's and '40's took place in such small numbers that inferences cannot safely be drawn from them. And if any increase of these diseases did in fact take place in those years, that would not prove that the Elbe water was not to blame, for, in fact, before 1848 water was freely taken from the river, which, in former times, may have been badly polluted upstream. . . . .
>
> Neither can the rise of gastro-intestinal diseases in March, 1895, decide the question, if the scant excess of deaths be given due weight, for in those first years of filtration the management of the waterworks still had difficulties, now entirely overcome, to contend with, arising in very cold weather with the cleaning of the filters. It appears, in fact, from reports in my possession on the bacteriological control of the filters in 1895, that in February and March of that year individual filters repeatedly worked imperfectly, so that a few of the infective agents of these diseases may have slipped through. . . . .
>
> On comparing the two tables on page 211 and page 220, it is found that the high stages of the river caused by melting snow [at certain times] did not have the slightest influence on the number of deaths from gastro-intestinal diseases, while in January, 1883, as also in the beginning of the year 1845, the increase of deaths from these diseases coincides with a much swollen river. Before drawing any conclusions from these observations, further experiments must be awaited, and the conditions in other cities be thoroughly compared.
>
> *Meanwhile we must be content to have established the fact that the unpurified city water has, until the inception of filtration, contributed heavily to the spread of gastro-intestinal diseases* (pp. 210–16). [The italics are ours.]

> The decline in infant mortality is of special interest because in this we see a result of the filtration of the drinking water which has exceeded all expectation and has materially enriched our knowledge of the propagation of gastro-intestinal disorders. . . . . If therefore the whole improvement . . . . cannot be ascribed to these diseases and hence to the results of better water, certainly the overwhelming majority of cases also belongs in this category (p. 310).

We quote also the following with reference to the relation between gastro-intestinal disorders and typhoid fever:

> Formerly, disturbances in the operation of the filters at the Altona waterworks repeatedly appeared, especially in very cold weather, which made the proper cleaning of the filters difficult or impossible. At such times unfiltered or insufficiently filtered

water entered the distribution system, whereupon the health of the people would react at once with the appearance of cases of gastro-intestinal disorder, a sure sign to the Altona physicians that two to three weeks later typhoid cases would follow (p. 234).

Examples of such outbreaks are given, characterized as sudden in onset, restricted to the Altona district, falling in seasons otherwise unfavorable to typhoid propagation, and as having been completely absent since the improvement of filtration in Altona.

A similar local and explosive typhoid outbreak occurred in Hamburg in 1893 ("Jahresbericht für 1893," p. 55). On a wharf on the south bank of the Elbe, where the laborers were provided, for drinking purposes, with Elbe water purified by a filter of special construction . . . . 100 laborers suddenly fell sick with gastro-intestinal disorder, and 19 of them developed typhoid. Closer investigation revealed the fact that shortly before the outbreak of the sickness the filter had been "cleaned" and that its efficiency had for a while been very much reduced (p. 235).

. . . . Instances from the winter season are much more characteristic, for then the influences of the summer heat have quite ceased. A few are summarized in the table below [Table 3].

[TABLE 3.]

DEATHS FROM GASTRO-INTESTINAL DISEASES AND CASES OF TYPHOID FEVER, BY WEEKS.

	WEEK NUMBERS [FROM BEGINNING OF EACH YEAR].																				
	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
1888-89																						
Gastro-intestinal diseases	28	57	31	21	15	10	17	43	46	36	28	24	17	11	15	10	43	54	83	60	21	..
Typhoid fever	42	32	46	83	46	54	32	33	46	92	75	48	41	50	40	30	45	41	55	80	112	57
1890																						
Gastro-intestinal diseases	..	..	..	..	..	..	..	..	..	..	..	..	17	24	17	42	64	67	29	17	12	8
Typhoid fever	..	..	..	..	..	..	..	..	..	..	..	..	34	35	34	28	35	35	48	44	43	24

From this it cannot be doubted, keeping in mind the foregoing instances and similar cases elsewhere (e.g., at the Tegel waterworks in Berlin, January to March, 1889 [account already quoted from "Jahresbericht für 1892"]), that typhoid fever and gastro-intestinal diseases are to be attributed to a common vehicle which can only be found in the public water-supply (p. 238).

3. Tuberculosis.

Especially surprising was the improvement [as to phthisis] in the period from the fourth to the sixth decade, when the sewerage and water-supply systems just completed must have been of very strong influence for general cleanliness (p. 285).

In tuberculosis the decline in mortality began long before 1872; but this progressive improvement has gone on at a distinctly brisker rate since the middle of the eighth decade, due no doubt to the fact that after the discovery of the tubercle bacillus the measures already in operation were more systematically applied. At the same time it is worthy of notice that it is maintained from the surgical side that since the filtration of the water the number of cases of bone and joint tuberculosis has diminished extraordinarily. Further observations should tell whether a causal connection really exists here. At any rate such a possibility cannot be excluded, since of course the sputa and bowel discharges of all the tuberculous reach the Elbe through the sewers, and tubercle bacilli just as well as typhoid bacilli could have been carried thence in the water to the people (p. 309).

4. Other Infectious Diseases.

In reference to "Inflammatory Diseases of the Respiratory Organs" ("Entzündliche Erkrankungen der Atmungsorgane") (not including phthisis):

> Unfortunately such a variety of diseases must be included under this title that only a very general orientation is possible (p. 101).
>
> The decline in these diseases since 1893 is very striking. Prior to that time the annual death-rate from these causes was 3 to 4 per thousand inhabitants, but now the mortality has dropped to 2 to 3 per thousand. What has worked this revolution is difficult to determine, as the picture of events [see diagram] is much confused by the large influenza epidemics of 1891, 1895, and 1900 (p. 103).
>
> The conditions with respect to diseases of the respiratory organs (exclusive of tuberculosis) are even more obscure [than for tuberculosis]. Still the striking improvement [shown by comparative rates for the two periods 1872–96 and 1896–1900] in this group, which includes very diverse forms of disease, must be accredited more to general sanitary improvements than to the filtration of the water (p. 310).

It is interesting to note that of all deaths from inflammatory diseases of the respiratory organs in the period 1872–1900, about 25 per cent occurred among infants under one year of age (pp. 133, 160).

In the quotations here given we believe that we have cited all of special interest or importance in reference to the effect of a purified water-supply upon the various infectious diseases in Hamburg. And we desire, on leaving this portion of the subject, to express our high appreciation of the thoroughness of the work of Dr. Reincke and his associates, which has thrown so much light upon this important subject.

VI. MR. MILLS'S FURTHER STUDIES ON THE WATER-SUPPLY AND TOTAL DEATH-RATE, ETC., OF LAWRENCE, MASSACHUSETTS, AND HIS ADDRESS TO THE CITY GOVERNMENT OF LAWRENCE, 1893–1902.

Ever since 1893 Mr. Mills had been making further observations and studies, some of which he had reported to his colleagues on the State Board of Health of Massachusetts as early as 1896. Several years later (July 3, 1902) in the course of an address before the city government of Lawrence, he read a statement of his results, from which we may quote the following striking paragraphs, published the next day in the Lawrence newspapers:

> The deaths from typhoid fever dropped from an average of 52 per year for the six years previous to the use of the filtered water to an average of 12 per year in the past six years. But this is only a small part of what has been accomplished. The deaths from all diseases in the city have, since the filter was built, averaged 19 annually per thousand of inhabitants, while in the six years previous to the building of the filter the deaths from all diseases averaged 24 per 1,000 annually. That is, in the years since you began to use filtered water there has been an average of 300 less deaths per year than there would have been if the death-rate had continued as before. . . . .
>
> When the United States Census Bureau of 1900 found that the deaths in Lawrence were, when they considered the increase in population, equivalent to more than 300 less deaths than in 1890, they wrote to your City Board of Health asking the cause, and were informed that the principal cause that they could indicate was the introduction of filtered water for the use of the city in 1893. They had reason for their conclusion when their records showed the deaths in 1892 to be 1,246 and the deaths of 1894 to be 925; a difference of 321 deaths from the year before to the year after the filter was completed.
>
> Since you began to drink filtered water the records show that there have been as many as 2,500 less deaths in the city than there would have been if the average death-rate of the previous six years had continued to this time; and this has been one of the sources of increase in population. . . .
>
> The decrease in deaths has not been limited to deaths caused by diseases which are known to be conveyed by water, nor to infectious diseases, but includes so broad a range of diseases that we must conclude that the general health of the people has been improved and their ability to resist and overcome disease has increased.

VII. DISCUSSION BY MR. ALLEN HAZEN, C.E., OF THE WATER-SUPPLY OF LAWRENCE IN RELATION TO THE TOTAL DEATH-RATE, 1901.

In the published discussion of a paper[1] presented by Messrs. Morris Knowles and C. G. Hyde at a meeting of the American Society of Civil Engineers, June 5, 1901, Mr. Hazen made the following statement:

> While the most striking reduction in the death-rate following the use of filtered water was in typhoid fever, the general death-rate showed a very considerable reduction. Table No. 26 shows the death-rate per thousand living for the seven years that the filter has been in operation, together with the corresponding rates for three preceding periods of seven years each.
>
> The reduction in the general death-rate in the last seven years, as compared with the seven preceding years, is several times as large as the reduction in the typhoid

---

[1] The Lawrence, Mass., City Filter: A History of Its Installation and Maintenance, *Trans. Am. Soc. C.E.*, 46, p. 316.

fever death-rate, and perhaps indicates the effect of the quality of the water on other diseases. The question as to how far this is due to the water-supply, and how far to improved general sanitary conditions, may be properly raised; but the very decided reduction at the time of the introduction of the filter, and the steadiness with which the rate has continued on a lower level since, seem to indicate that the water-supply had something to do with the reduction, and that the coincidence was not accidental.

VIII. A GRAPHICAL DEMONSTRATION OF THE LAWRENCE PHENOMENA PUBLISHED BY MR. MILLS, 1904.

In April, 1904, Mr. Mills showed to one of the authors (W. T. S.), who was about to give in Lawrence a public address on the water-supply of that city, the diagram herewith reproduced (with addition of recent years by the authors) as Chart 1, and kindly permitted him to make from it a lantern slide which he then used and has since used from time to time in his lectures. This diagram, which was afterward published with slight additions in the Annual Report of the Water Board of Lawrence for 1906, illustrates in a very striking way the Mills-Reincke phenomenon to which we have now repeatedly referred.

IX. FORMULATION OF HAZEN'S THEOREM, 1904.

At the International Engineering Congress held at St. Louis in October of the same year, Mr. Allen Hazen took an important step in advance, and formulated a numerical expression for the comparative effect of water purification upon typhoid fever mortality and total mortality. He had already approximated such an expression in his statement made in 1901 and quoted above that—

> the reduction in the general death-rate . . . . is several times as large as the reduction in the typhoid fever death-rate.

On account of its importance as the first attempt, so far as we are aware, to reduce to a quantitative statement the Mills-Reincke phenomenon, we shall quote in detail that part of Mr. Hazen's study which concluded with the formulation as above mentioned of a numerical expression of the relation of total mortality to typhoid fever mortality.

> The general death-rate, as might be expected, is also reduced, and it is reduced to a greater extent than can be accounted for in the reduction of the typhoid fever rate. The percentage of reduction in the general death-rate is less than it is with typhoid

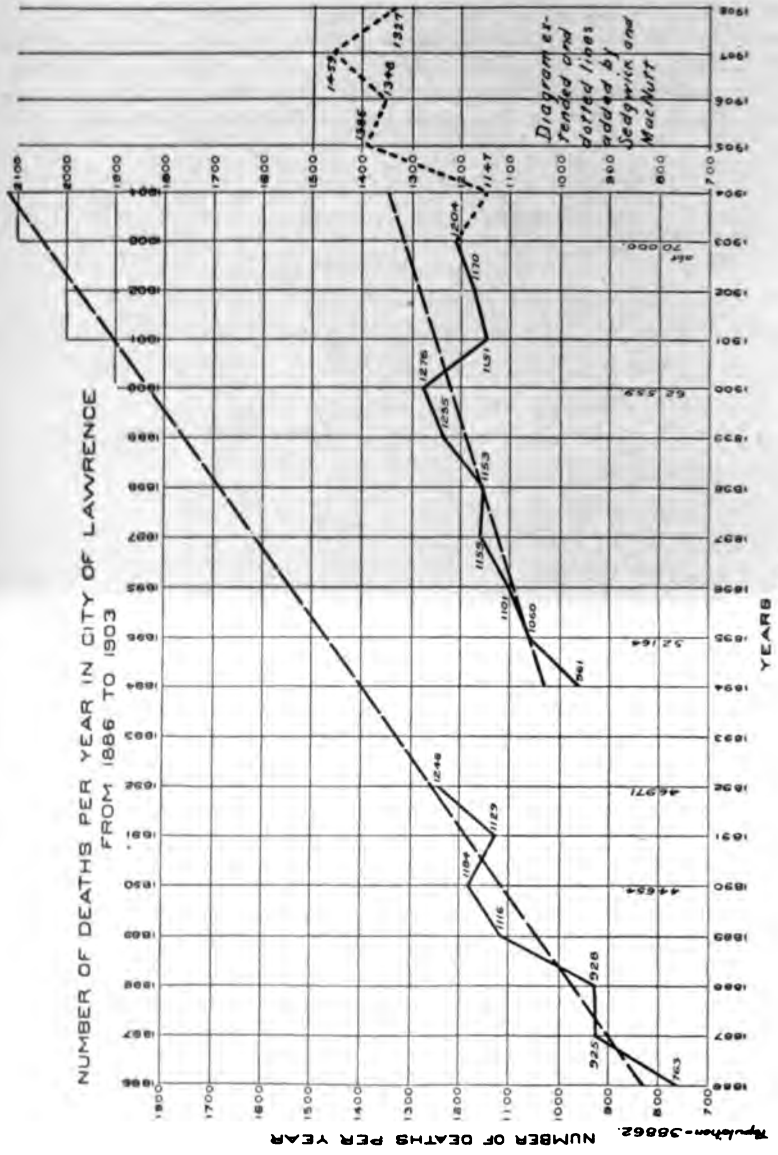

NUMBER OF DEATHS PER YEAR IN CITY OF LAWRENCE
FROM 1886 TO 1903
YEARS
NUMBER OF DEATHS PER YEAR
Population - 38862.
Diagram extended and dotted lines added by Sedgwick and MacNutt
763
925
928
1116
1184
1129
1246
961
1060
1101
1155
1153
1235
1276
1151
1170
1204
1147
1386
1348
1459
1327
44654
46971
52164
62559
abt 70000.

CHART I.

fever and it is therefore more difficult to follow the relation, and the reduction attributable to the change in water can be ascertained with less certainty.

Tables 5 and 6 show the general death-rates and the death-rates from typhoid fever in a number of cities, before and after radical improvements in their water-supplies. In four cases, two in Europe and two in the United States, the changes were made by the installation of sand filters. In the other cases the changes were from polluted river supplies to upland waters from unpolluted sources, or to ground-water. The year of change (when both the old and new supplies were in use) is omitted in each case. At Lowell, Mass., where the change was more gradual, two years are omitted, and at Hamburg, the cholera year, 1892, which immediately preceded the year in which the filters were put in service, is also omitted from the comparison.

TABLE 5.

DEATHS FROM TYPHOID FEVER PER 100,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Zurich, Switzerland . . . . Filtration	1885	76	10	87
Hamburg, Germany . . . . Filtration	1892–93	47	7	85
Lawrence, Mass . . . . . . Filtration	1893	121	26	79
Albany, N.Y. . Filtration	1899	104	28*	73
Lowell, Mass., river water to ground-water	1895–96	97	21	78
Newark, N.J., river water to upland water .	1892	70	16	77
Jersey City, N.J., river water to upland water	1896	77	24	69
Averages		85	19	78

* Four years.

The reductions in death-rates with the installation of filters have been quite as great as in those cities where the new sources of supply were from unpolluted sources. The average reduction in the typhoid rate was 66 per 100,000. The reduction in the general death-rate was 4.7 per 1,000 or 470 per 100,000.

TABLE 6.

DEATHS FROM ALL CAUSES PER 1,000 PER ANNUM.

Place	Date of Change	Five Years before Change	Five Years after Change	Percentage of Reduction
Hamburg, Germany . . Filtration	1892–93	24.0	17.7	26
Lawrence, Mass . Filtration	1893	24.4	20.0	18
Albany, N.Y. Filtration	1899	22.3	18.4*	17
Newark, N.J., river water to upland water	1892	25.1	22.1	12
Jersey City, N.J., river water to upland water	1896	25.4	19.3	24
Lowell, Mass., river water to ground water	1895–96	25.1	20.5	18
Averages		24.4	19.7	19

* Four years.

While the reduction in the typhoid rate is 66 per 100,000, that in the general death-rate is 4.7 per 1,000 or 470 per 100,000, or seven times as much. Where there is one less death from typhoid fever there are six less from other causes.

The writer believes that the whole of the reduction in the typhoid rate should be attributed to the change in water-supply, because cities similarly situated, which have

> not improved their supplies, have experienced no permanent reduction in their typhoid fever rates. With the general death-rate the case is different. Improved general sanitary conditions have reduced the death-rates in recent years, and the normal reduction in a period of six years, which represents the average elapsed time between the first and second series of results, would account for a part of the reduction in the general death-rate.
>
> The average reduction in the general death-rate between 1890 and 1900 in eighteen cities having from 50,000 to 300,000 inhabitants, in New England, New York, and New Jersey, which made no radical change in their water-supplies, was 2.28 per 1,000. This is computed from the Report on Vital Statistics in the United States Census of 1900. Assuming a uniform decrease in rate in the interval, the average, or what we may call the normal, reduction, in 6 years would have been 0.6 of this, or 1.37 per 1,000. In comparison with this, in five cities where the water was radically improved, the reduction in the same period was 4.4 per 1,000. The results may be tabulated as follows:

	Death-Rate per 100,000 Living
Reduction in total death-rate in five cities with the introduction of a pure water-supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated but with no radical change in water-supply	137
Difference, being decrease in death-rate attributable to change in water-supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water-supply	232

> This computation indicates that *where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided.* [Italics our own.] This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water-supply, used freely and with confidence, results in a better general tone in the systems of the population, and so indirectly to a lower death-rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water-supply ("Trans. Am. Soc. C.E.," 54D pp. 151–53).

The quantitative relation thus arrived at by Mr. Hazen and italicized above, seems to us to deserve, because of its far-reaching importance, some special designation. We have therefore ventured to apply to it in our preliminary paper[1] the term *Hazen's Theorem.*

Mr. Hazen further added, in the discussion on this paper:

> The writer agrees with Messrs. [E. O.] Jordan and G. W. Fuller that it is most important that further study be made of the effect of water-supply upon other diseases than typhoid fever. The statistics certainly indicate a much wider influence of water-supply upon public health than has been generally admitted; and it would seem as if studies might be made to ascertain the facts more definitely (*ibid.*, p. 251).

---

[1] *Science*, August 14, 1908.

X. OTHER DATA AND DISCUSSIONS BEARING ON THE GENERAL SUBJECT.

We have not been able to find later than the formulation in 1904 of Hazen's theorem any definite advance in the analysis of the underlying Mills-Reincke phenomenon or any attempt at a general proving of the theorem itself. It enunciation has, however, caused occasional discussion and called forth some confirmatory data from various quarters. Without attempting to quote all such data and discussions we shall summarize the more important.

Professor Edwin O. Jordan, in the discussion on Mr. Hazen's St. Louis paper, made the following remarks:

> Mr. Hazen's computation which indicates that, in addition to the reduction in deaths from typhoid fever, there occurs a similar reduction in deaths from other causes, and that this also is attributable to a change in the water-supply, is certainly very striking. There is one suggestion which the writer would like to offer concerning a possible explanation of this circumstance.
>
> It is well known that the obscure character and variable symptoms of certain cases of typhoid fever lead not uncommonly to a mistaken diagnosis. There is no doubt that in every considerable body of vital statistics some cases of genuine typhoid fever are reported under other names. It need hardly be said that this is particularly true as regards the deaths reported under the captions "typho-malarial fever," "malarial fever," and similar designations. In the Northern United States, the majority of the deaths reported under these headings are deaths from typhoid fever. The effect of filtration well illustrates this point. In the city of Albany, N.Y., there were 37 deaths reported under the heading "malarial diseases" in the four years, 1891–94, and 23 deaths in the four years, 1895–98, while for the four years following filtration (1900–1903), there were but two deaths under the same head.
>
> It must be remembered also that a marked improvement in methods of diagnosis of typhoid fever has taken place during the last decade. One result of this has been that deaths formerly reported as occurring from other causes are now correctly reported as due to typhoid fever. This transfer to the column of typhoid deaths naturally diminishes the deaths reported from general causes and must, at least, partly explain the relation pointed out by Mr. Hazen. It may also serve to explain why the apparent reduction in deaths from typhoid fever is sometimes less than would be reasonably anticipated. The suggestive facts brought out in the paper indicate that other items under the reported deaths in official health reports might repay examination ("Trans. Am. Soc. C.E.," 54D, pp. 206, 207).

Three years later the phenomenon observed at Lawrence by Mr. Mills was referred to in a paper[1] by Mr. H. W. Clark, who called attention to a similar decline following the introduction of filtration at Albany, N.Y.

---

[1] *Monthly Bull. Mass. State Board of Health*, Sept., 1907, p. 242.

On November 6, 1907, Mr. Edward E. Wall, in a paper[1] presented before the American Society of Civil Engineers, wrote as follows:

> Allen Hazen, M. Am. Soc. C.E., estimates that where one death from typhoid has been avoided through an improved water-supply probably two or three deaths from other diseases have been avoided. The following record seems to indicate a higher proportion of decrease than Mr. Hazen's estimate would give:
>
> ANNUAL MORTALITY RECORD, ST. LOUIS, MO., 1900–1906, FROM DISEASE ALONE.
>
> [Chemical precipitation introduced in 1904.]

1900	9,217	1904	10,695
1901	9,016	1905	9,545
1902	9,654	1906	9,214
1903	10,320		

Mr. Mills's observation of the phenomenon at Lawrence was again referred to by Mr. Stephen DeM. Gage in the discussion on a paper on filter operations at Lawrence, Mass., presented by Messrs. M. Knowles, M. F. Collins, and A. D. Marble before the New England Water Works Association, February 12, 1908:

> In addition a very material reduction has occurred in the total death-rate of the city, a reduction so different in character from that gradual decrease due to increased appreciation of municipal sanitation which has taken place throughout the State of Massachusetts and following so closely the introduction of filtered water that it can only be explained by attributing it to the improvement in water-supply ("Jour. N.E. Water Works Assn.," 22, p. 232).

Mr. Gage accompanied his statements with a diagram showing the decline in the typhoid fever death-rate and in the total death-rate at Lawrence for the period 1880–1905.

Finally, as the only other reference we have been able to discover, we may record the observation based on statistics, by Mr. E. L. Grimes, City Engineer of Troy, N.Y., and reported at the same meeting, that following the extension and sanitary improvement of the water-supply of that city there occurred a distinct decrease, not only in the deaths from typhoid fever, but also in the deaths from cholera infantum, diarrhea, diseases of the digestive organs, and of children under five years of age.[2]

XI. A RECAPITULATION OF THE LITERATURE, AND A BRIEF OUTLINE OF THE WORK OF THE AUTHORS.

A review of the foregoing sections leads irresistibly to the conclusion that Messrs. Mills, Reincke, and Hazen, in their observations and studies already described, have brought to light phenomena of the very first importance in sanitary science. There appears to be no escape from the conclusion that the purification of polluted public water-supplies reduces the general death-rate much more than it would be reduced by the saving of deaths from the commonly recognized water-borne diseases, typhoid fever and Asiatic cholera, alone. The question naturally arises, to what extent is the general death-rate reduced? And this simple question Hazen's theorem undertakes to answer. Another question which naturally arises is, in what particular diseases does this reduction take place? And this question we shall ourselves undertake to answer.

---

[1] "Water Purification at St. Louis, Mo.," *Trans. Am. Soc. C.E.*, 60, p. 182.

[2] *Jour. N.E. Water Works Assn.*, 22, p. 183.

As yet very few students of public health science are aware of the extent of the studies of Reincke and Mills; and no one, so far as we know, has hitherto undertaken any thorough confirmation of their results. We have therefore ventured to make a study of this kind, first critically examining all the evidence in our possession relating to the Mills-Reincke phenomenon and Hazen's theorem; and then, having found the latter sound and conservative, passing on to the study of fresh examples, to test its scope and range.

Following the historical development of the subject we have naturally begun with the data afforded by the city of Hamburg.

XII. A GRAPHICAL DEMONSTRATION AND DISCUSSION, BY THE AUTHORS, OF THE HAMBURG PHENOMENA.

As a detailed demonstration of the mortality phenomena before and after the introduction of filtration at Hamburg we have taken statistics from the "Sanitary History of Hamburg in the Nineteenth Century" and plotted from them in Chart 2 the curves for certain important causes of death. On the vertical lines, corresponding to the middle of each year, are plotted the average annual death-rates. The period of unfiltered water is indicated by the heavy black bars beginning on the left and crossing more than one-half the diagram. The period of filtered water-supply is indicated by the clear spaces following these heavy black bars. The scale employed, it must be observed, is the same for all the curves except the two lowest, thus facilitating comparisons. In order to save space, the unused portion of the scale below each curve except the uppermost has been cut off.

Hamburg is well known in the annals of sanitary science on account of its great Asiatic cholera epidemic of 1892. A slow sand filter was at that time in process of construction, and the epidemic of cholera caused a precipitate activity in construction which resulted in the rapid completion of the filter and the beginning of its operation in May, 1893. A brief description of the water-supplies of Hamburg and the neighboring city of Altona is given by Dr. Reincke in his Annual Report for 1892 and translated by Mr. Hazen in an appendix to his "Filtration of Public Water-Supplies." A fuller account is given in the "Sanitary History of Hamburg in the Nineteenth Century." We need only recall that previous to the introduction of filtration in Hamburg the public water-supply was taken from the (tidal) Elbe River at a point about four miles above the outfalls of the main trunk sewers of Hamburg and Altona. In 1893 the intake was moved about a mile farther upstream, and while the river at these points was probably not ordinarily heavily polluted, Dr. Reincke brings conclusive evidence (quoted by us, pp. 495–97, 500–503) to show that at certain times of high tide and low river the sewage of Hamburg and Altona was driven upstream and came at such times directly to both intake points. By filtration the effects of the pollution from this source have been eliminated. As the diagrams of death-rates in Chart 2 speak for themselves, we need comment on them only briefly.

From the first curve it will be seen that the typhoid fever death-rate fell from an average of about 30 in the five years prior to 1893 to a rate after filtration of less than 10 per 100,000.

In inflammatory diseases of the respiratory organs there was an extraordinary drop, and the rates from this cause of death have continued on a much lower level since 1893. The fall in the mortality from these diseases is so striking that we have continued the computation of the rates for a few years beyond the last date shown in the plate, and have found that the low level assumed after introduction of filtration was steadily maintained. The following rates are computed from data from the Imperial Health Office Bulletin, "Sterbefälle im Deutschen Reiche"; for 1901, 228; 1902, 215; 1903, 196; 1904, 188; and may readily be added by the reader if he so desires. (To avoid misunderstanding of the method of plotting

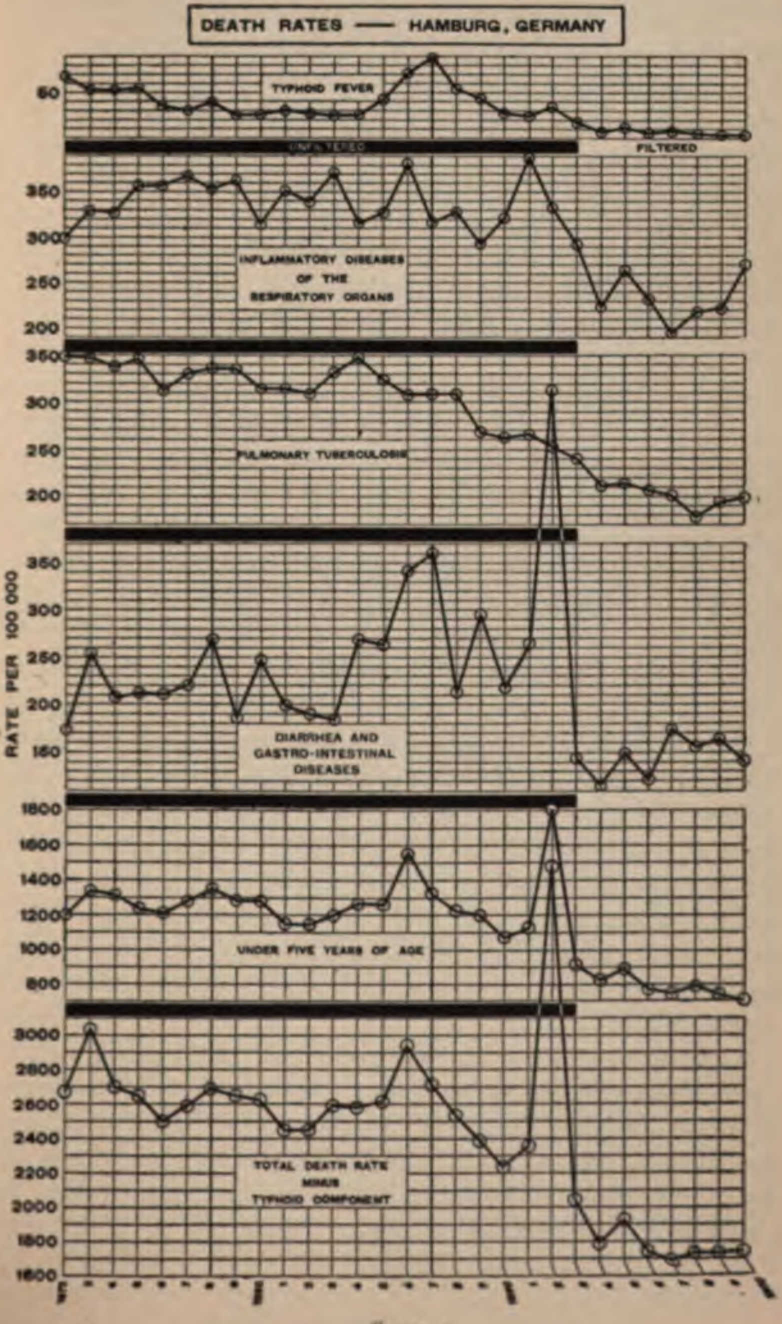

DEATH RATES —— HAMBURG, GERMANY
TYPHOID FEVER
50
UNFILTERED
FILTERED
INFLAMMATORY DISEASES OF THE RESPIRATORY ORGANS
350
300
250
200
PULMONARY TUBERCULOSIS
350
300
250
200
RATE PER 100 000
DIARRHEA AND GASTRO-INTESTINAL DISEASES
350
300
250
200
150
UNDER FIVE YEARS OF AGE
1800
1600
1400
1200
1000
800
TOTAL DEATH RATE MINUS TYPHOID COMPONENT
3000
2800
2600
2400
2200
2000
1800
1600

Chart 2.

we must again caution the reader that the unused scale below this, as below subsequent curves, has been cut off.)

Pulmonary tuberculosis, which had been gradually declining for ten years, showed a somewhat greater rate of decline for the year following the introduction of filtration. Whether the purification of the water-supply played any considerable part in this we are unable, from the Hamburg data alone, to determine, but our studies in later sections of this paper on Lawrence and Lowell, Massachusetts, give good reason for supposing that at Hamburg also the purification of the water-supply had a certain effect in lowering the mortality from phthisis.

The title "diarrhea and gastro-intestinal diseases," as used in Chart 2, corresponds to the German *Durchfall und Brechdurchfall*.[1] The curve for this cause of death shows very strikingly the influence of the change to a purified water-supply. From an average rate immediately before filtration of about 300 it dropped suddenly by a full half, at which level it has since continued to 1900. We are forcibly reminded of Dr. Reincke's remark, already quoted, that "in no other diseases did the favorable influence of the better water-supply introduced in 1893 stand out so clearly as in these."

The curve for the death-rate of children under five years of age shows a similarity to that for diarrhea and gastro-intestinal diseases, including as it does a large number of deaths from the latter. Thus the drop in 1894 and the continued lower level of subsequent years is seen in a degree which, when the difference of the scales is taken into account, is as striking here as in the curve just above. A considerable share of this mortality is also contributed by inflammatory diseases of the respiratory organs, and a certain similarity between the two curves may readily be traced. We again call attention to the fact that the scale in this diagram, like all the others in the chart except the topmost, is not extended fully to the true base line.

Finally, the diagram for total death-rate minus typhoid component illustrates strikingly that drop following the introduction of filtration which we have named the Mills-Reincke phenomenon, as observed at Hamburg by Reincke. It is at once seen how sudden, how great, and how permanent was the reduction in this death-rate.

---

[1] See note, p. 494.

The rate had reached a miminum in 1900, and was on its way up again when the influence of filtration came into play. How great numerically the reduction actually was, and how far it is to be attributed to the purification of the water-supply, is discussed below.

In order to carry the graphical demonstration still farther, we have plotted in Chart 3 the death-rates for age-groups, which rates are reckoned more accurately—on the population in each age-group—than on the total population. The Mills-Reincke phenomenon is here seen to affect all age-groups—that under one year, however, most notably. This is evidently to be accounted for very largely by the relation of water-supply to diarrheal and gastro-intestinal diseases, as explained by Dr. Reincke (secs. iv and v), 90 per cent of these diseases having occurred among infants under one year of age and constituting about one-quarter of the whole mortality of the latter.

Thus from Charts 2 and 3 it is seen that all of Dr. Reincke's statements on the decline in total death-rate, in infant mortality, and in the other diseases mentioned by him are fully substantiated. More than that, the data afford a basis for going somewhat beyond his statements, which, as we shall show, were characterized by much caution.

It may be objected that there were, possibly, at the time under consideration, declines in the total death-rates of German cities in general; in order, therefore, to show the extraordinary character of the drop at Hamburg we present the table on p. 519 for the ten largest cities of Germany (according to the Census of 1890), showing their average total death-rates for two periods of three years each, before and after the cholera years and introduction of filtration at Hamburg, the corresponding typhoid fever rates also being given.

It is at once evident how remarkable the reductions were at Hamburg, both in typhoid fever and in the total death-rate. Taking the typhoid fever rate as an index of quality of water-supply, Hamburg is shown to have been much worse off than any other city during the first period. In the second period all show declines, but that in Hamburg stands far above them all, having been six times as great as the average

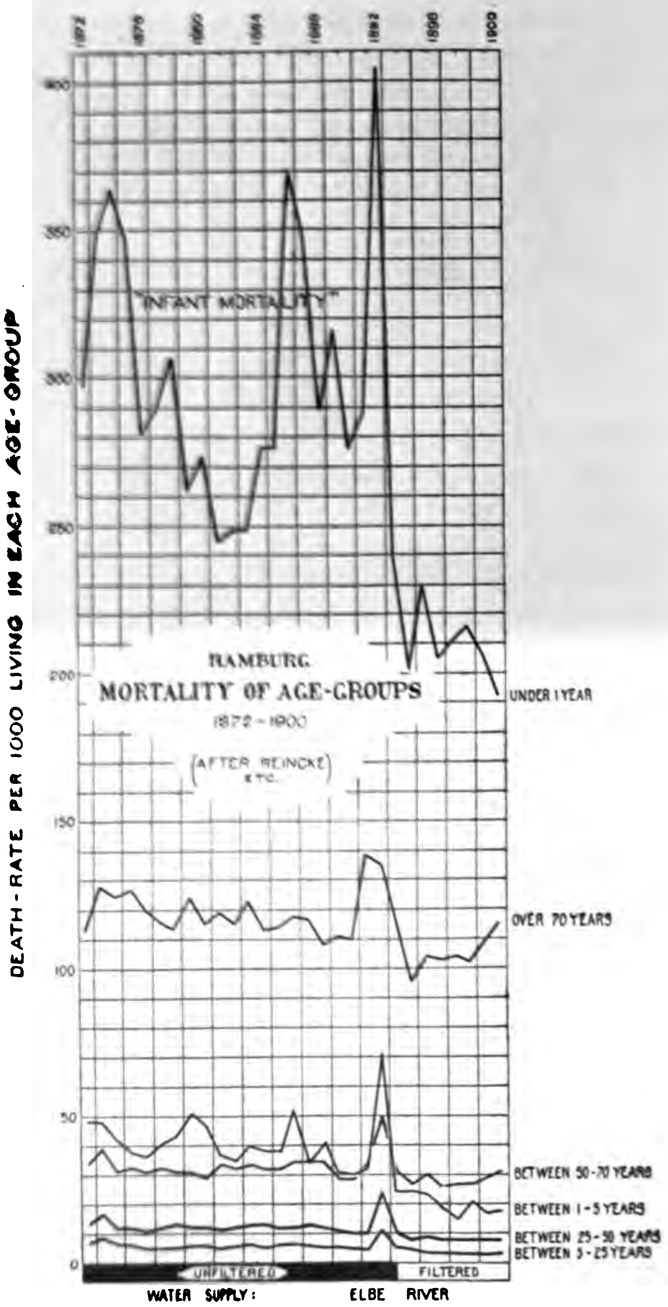

1872
1876
1880
1884
1888
1892
1896
1900
400
350
300
250
200
150
100
50
0
DEATH-RATE PER 1000 LIVING IN EACH AGE-GROUP
"INFANT MORTALITY"
HAMBURG
MORTALITY OF AGE-GROUPS
1872-1900
(AFTER REINCKE ETC.)
UNDER 1 YEAR
OVER 70 YEARS
BETWEEN 50-70 YEARS
BETWEEN 1-5 YEARS
BETWEEN 25-50 YEARS
BETWEEN 5-25 YEARS
UNFILTERED
FILTERED
WATER SUPPLY:
ELBE RIVER

CHART 3.

for the other nine cities. In total death-rate the drop at Hamburg is much greater than that of any other city, and over four times as great as that of the other nine, and this over and above the results of sanitary improvements going on in the other cities.

TABLE 4.

TEN LARGEST GERMAN CITIES	TYPHOID FEVER DEATH-RATES PER 100,000			TOTAL DEATH-RATES PER 1,000		
	1889–91 incl.	1894–96 incl.	Decrease	1889–91 incl.	1894–96 incl.	Decrease
1. Berlin	13	5	8	21.8	20.0	1.8
2. **Hamburg**	**31**	**7**	**24**	**23.1**	**19.2**	**3.9**
3. Munich	8	3	5	27.6	25.2	2.4
4. Breslau	12	8	4	28.8	27.3	1.5
5. Leipzig	13	9	4	20.0	21.7	−1.7
6. Cologne	13	7	6	25.8	24.1	1.7
7. Dresden	8	6	2	20.8	21.0	−0.2
8. Magdeburg	20	9	11	24.6	23.7	0.9
9. Frankfort-on-the Main	8	5	3	18.9	17.6	1.3
10. Hanover	8	7	1	19.6	19.3	0.3
Nine cities exclusive of Hamburg (average)	**11**	**7**	**4**	**23.1**	**22.2**	**0.9**

Typhoid fever death-rates, with exception of Magdeburg, from G. C. Whipple's "Typhoid Fever," App. XVI; other death-rates computed from "Statistisches Handbuch deutscher Städte." The Hamburg figures refer to the *Stadt* exclusive of suburbs, and hence do not quite agree with the rates given by Dr. Reincke for the whole Hamburg district (*Staat*).

Several questions naturally arise at this point. How great was the reduction at Hamburg, not only in the total death-rate, but also in the specific diseases? And what causes contributed most to the total reduction? In answer to these questions we submit in the table on p. 520 a statistical synopsis which we have made of the Hamburg phenomena. The cholera year (1892) and year of introduction of filtration (1893) are omitted, and the means of five years before and five years after are computed, so as to be comparable with our studies of Lawrence and Lowell in sec. xvi.

Of the total reduction, i.e., in the general death-rate, we find that the chief components for specific causes of death are as follows: 19 per cent contributed by diarrhea and gastro-intestinal diseases; 15 per cent by inflammatory diseases of the respiratory organs; 12 per cent by phthisis; 8 per cent by diphtheria; 6 per cent by typhoid fever; and 40 per cent by other causes of death. Viewing the total reduction from the standpoint of age of decedents, we find that 38 per cent falls in the infant mortality under one year of age (as reckoned on the total population).

For every death less from typhoid fever after filtration there were 15.8 deaths less from other causes, but as this figure is merely crude—i.e., has not been corrected for the decrease in mortality that would have taken place independently of water-supply purification—it cannot properly be substituted as the numerical member of Hazen's theorem (see p. 510). It is, however, so much greater than the figure suggested by Mr. Hazen that we are led to venture a partial explanation in the fact that there was not as much typhoid fever to begin with at Hamburg as at Lawrence and Lowell, whether the periods before or after filtration be compared; so that typhoid fever played a smaller part, in proportion, at Hamburg, than in the two American cities upon which, among others, Mr. Hazen's estimate was based.

TABLE 5.

DEATH-RATES, GENERAL AND SPECIFIC, IN HAMBURG BEFORE AND AFTER ADOPTION OF FILTRATION.
Computed from the "Sanitary History of Hamburg in the Nineteenth Century."

Cause of Death	Mean Death-Rate 1887–91 Incl.*	Mean Death-Rate 1894–98 Incl.*	Percentage Decrease
All causes	2444	1,774	27
Asiatic cholera	No deaths	except in 1892 and	1893
Typhoid fever	47	7	85
†Diarrhea and gastro-intestinal diseases	270	143	47
†Infant mortality (under 1 year)	304	213	30
Inflammatory diseases of the respiratory organs	320	220	31
Phthisis	253	202	20

---

* Rates are per 100,000 of population except in the case of infant mortality, for which they are reckoned per 1,000 living under one year of age.

† These two titles overlap; one-quarter of the "infant mortality" is due to "diarrhea," and nine-tenths of the deaths from the latter fall under "infant mortality."

To sum up the Hamburg phenomena, we return again to the striking demonstration of the Mills-Reincke phenomenon as observed there by Dr. Reincke. This consisted in a sudden and permanent drop in the total death-rate minus typhoid component in 1893, an effect observable even in the rate for that year. The whole trend since 1872 of all the curves which we have exhibited, with the exception of that for pulmonary tuberculosis, was changed, each one pitching rapidly and immediately downward and assuming a distinctly lower level thereafter. We refer again to Dr. Reincke's comments on these phenomena as summarized in the preceding pages. We may here anticipate, and say that after our studies on other cities set forth in the following sections, we shall be forced to conclude that—except in respect to diarrhea and gastro-intestinal diseases and the recognized water-borne diseases, typhoid fever and Asiatic cholera—Dr. Reincke attributed to the purification of the public water-supply much less than its true share in the remarkable reduction in the total and specific death-rates of Hamburg.

XIII. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LAWRENCE PHENOMENA

We have made a careful study of the vital statistics of the city of Lawrence, where the Mills-Reincke phenomenon was first observed by Mr. Mills, following the introduction of filtration in 1893. In addition to Lawrence we have taken Lowell, Mass., where the public water-supply was also purified about the same time by a different method, i.e., substitution of unpolluted ground-water for polluted river water. Finally, we have taken the city of Manchester, N.H., as being in every important respect similar (as we shall show) to the two cities just mentioned and therefore an excellent norm for comparison. For all of these cities accurate vital statistics are fortunately obtainable. We have based our computations upon substantial foundations, viz., the populations given by the U.S. Census for 1880, 1890, and 1900, and the Massachusetts State Census for 1885, 1895, and 1905, computing the populations for the intermediate years by the "arithmetical" method of the U.S. Census.[1] The possibility of important errors arising from this method of computing populations for intercensal years will be discussed in section xviii.

The cities of Lawrence, Lowell, and Manchester, all manufacturing cities devoted chiefly to textile industries, are situated in the valley of the Merrimac River, a large, swift stream draining a considerable portion of southern New Hampshire and northern Massachusetts. The first two cities are especially well known through the studies on typhoid fever made there by the Massachusetts State Board of Health, and published in the Report of the Board for 1892. The three cities are so similar in size, character of population, industry, and climatic conditions, that they are particularly favorable for purposes of sanitary comparison. Three cities more similar in almost every respect could hardly be found elsewhere. In one important rticular, however, they have differed—viz., in their water-supplies and, as we shall see below, this fact, in connection with their se similarity in other respects makes their experience almost ivalent to a laboratory experiment. Lawrence, previous to

---

[1] The merit of this method as compared with certain others in vogue is discussed in Twelfth Census, *Bull. No. 135*, "Methods of Estimating Population."

TABLE 6.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†39,151												
1883	38,078	850	28	60	9	147	57						
1884	38,919	892	19	68	13	142	73						
1885	†38,862	774	17	67	17	163	44						
1886	40,020	763	23	45	14	125	55						
1887	41,178	925	47	74	17	132	71						
1888	42,337	928	48	95	16	134	77	11	17	42	54	29	13
1889	43,495	1,116	55	75	10	110	96	170	23	52	65	17	14
1890	†44,654	1,184	60	117	28	114	96	78	19	74	58	14	20
1891	46,156	1,129	55	133	30	91	101	50	34	69	61	13	24
1892	47,658	1,246	50	156	27	95	130	28	30	94	43	20	10
Change: 1893	49,160	1,184	39	161	15	113	102	23	29	65	38	23	21
Water-supply, filtered:													
1894	50,662	961	25	88	17	88	101	16	34	56	46	23	17
1895	†52,164	1,060	18	109	23	113	100	14	29	Not given			
1896	54,243	1,101	14	127	32	105	103	25	40	47	62	20	20
1897	56,322	1,150	14	138	26	93	124	47	27	52	73	19	19
1898	58,401	1,153	14	86	30	101	119	63	39	64	82	18	22
1899	60,480	1,235	21	119	36	123	111	64	35	87	87	19	25
1900	†62,559	1,276	13	138	43	116	147	35	34	48	102	19	37
1901	64,057	1,151	13	126	34	108	‡	17	40	44	103	12	23
1902	65,555	1,170	15	169	47	107	‡	12	49	32	87	8	21
1903	67,054	1,226	23	127	36	117	‡						
1904	68,552	1,147	11	150	31	111	‡						
1905	†70,050	1,386	15	203	39	107	‡						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lawrence Board of Health. For certain of the less important causes only the period 1888–1902 inclusive has been taken, the spaces for the remaining years being left blank. Total deaths in this and subsequent Tables 9 and 12 are exclusive of stillbirths.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports.

1893, had taken its water-supply directly from the polluted Merrimac River only nine miles below the sewers of Lowell, but introduced in that year slow sand filtration; Lowell changed in the years 1894 and 1895 from the same polluted river to a pure ground-water; while Manchester had, throughout the period which we shall consider a surface-water supply of good quality.

The statistics for Lawrence for the period which we have studied are given in Tables 6 and 7.

From these figures we have plotted upon diagrams shown in Chart 4 the death-rates from various causes in Lawrence from 1883–1895 inclusive—a period, that is to say, including the year of the sudden change from an unfiltered to a filtered water-supply, and covering the 10 years before, and 12 years after, that event.

TABLE 7.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LAWRENCE, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,181	72	154	23	377	146						
1884	2,292	49	175	33	365	188						
1885	1,992	44	172	44	419	113						
1886	1,907	58	112	35	312	137						
1887	2,246	114	180	41	320	172						
1888	2,192	113	224	38	317	182	26	40	99	128	60	31
1889	2,566	126	172	23	253	221	391	53	120	140	30	32
1890	2,652	134	262	63	255	215	175	43	166	130	31	45
1891	2,444	119	288	65	197	219	108	74	149	132	28	52
1892	2,614	105	327	57	190	273	59	63	197	90	42	21
Change: 1893	2,408	79	328	31	230	208	47	59	132	77	47	43
Water-supply filtered:												
1894	1,807	40	174	34	174	199	32	67	111	91	45	34
1895	2,031	35	209	44	217	192	27	56	...	...	..	..
1896	2,030	26	234	59	194	190	46	74	87	114	37	37
1897	2,058	25	245	46	165	220	84	48	92	130	34	34
1898	1,974	24	147	51	173	204	108	67	110	141	31	38
1899	2,042	35	197	60	203	184	106	58	144	144	31	41
1900	2,040	21	221	69	185	235	56	54	77	163	30	59
1901	1,797	20	197	53	169	†	27	62	69	161	19	36
1902	1,785	23	258	72	163	†	18	75	49	133	12	32
1903	1,828	34	190	54	175	†						
1904	1,673	16	232	45	162	†						
1905	1,979	21	290	56	153	†						

* Computed from preceding table.

† Title discontinued in reports. Slow sand filter went into operation September, 1893.

The method of plotting is the same as that in the chart for Hamburg, the vertical lines upon which the rates are plotted representing the middle of each year, and the period of the use of unfiltered Merrimac River water being shown by a black bar running to September, 1893, when filtration was introduced. The scale employed is the same for all curves except the lowest; and, in order to save space,

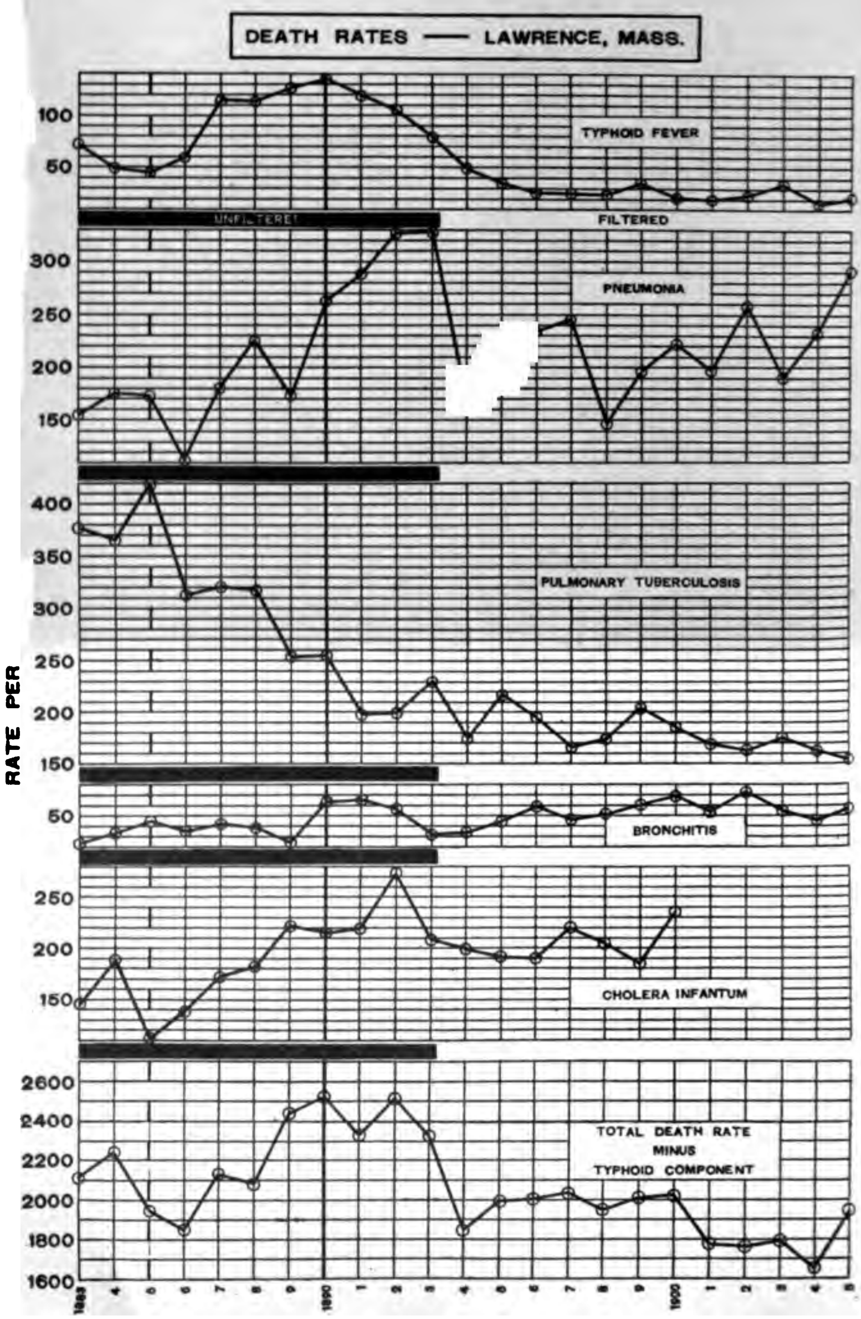

DEATH RATES — LAWRENCE, MASS.
100
50
TYPHOID FEVER
UNFILTERED
FILTERED
300
250
200
150
PNEUMONIA
400
350
300
250
200
150
PULMONARY TUBERCULOSIS
RATE PER
50
BRONCHITIS
250
200
150
CHOLERA INFANTUM
2600
2400
2200
2000
1800
1600
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
1883
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5

CHART 4.

the unused portion of the scale below each curve has been cut off, so that no base-lines are shown.

If we now proceed to analyze the different curves, we find that typhoid fever, which reached epidemic proportions of large magnitude in 1890, declined even before the introduction of the filter, as might naturally have been expected; but immediately afterward sank lower than for many years, and has since remained on a comparatively low level.

The curve for pneumonia is particularly interesting and striking, for it shows that this disease previous to 1893 had been rising by leaps and bounds most of the time since 1885, and had reached very large proportions in 1893. With the introduction of a purer water-supply pneumonia immediately fell back to a point lower than it had shown since 1889; and, altho it rose again somewhat, remained on a comparatively low average for the next 10 years.

Pulmonary tuberculosis was falling rapidly prior to the introduction of filtration, and continued to fall, tho more slowly, afterward. Altho in the curve any decline in phthisis consequent on water purification is so obscured by the effect of improvement in all sorts of other sanitary conditions that it cannot be directly demonstrated, nevertheless, as we showed in our paper entitled "An Apparent Connection between Polluted Public Water-Supplies and the Mortality from Pulmonary Tuberculosis" (referred to above, p. 491), a distinct effect of the filtration of the water-supply appears in this disease also. The evidence upon which this conclusion is based—as will be seen by reference to the above-mentioned paper, or to sec. xvi of the present paper where the same data are presented—is drawn from an analytical comparison with Manchester (*vide supra*) as a norm.

The curve for bronchitis shows no noteworthy phenomena beyond the lowness of the rates for 1893, 1894, and 1895 as compared with the three years next preceding. For this disease also a comparison with some other city such as Manchester as a control is required and is given beyond.

Cholera infantum, which was quite high for several years before the introduction of filtration, was somewhat lower for a number of years afterward.

When we come to the curve at the bottom of the chart we find a striking demonstration of the Mills-Reincke phenomenon. For we see that during the four years previous to the introduction of filtration the total death-rate had been very high, sometimes a little exceeding and sometimes falling a little below 24 per 1,000, a figure of notable height even if all the typhoid fever deaths had been included. Neglecting the year 1893, inasmuch as this was a year characterized partly by polluted and partly by purified water-supply, and beginning with 1894, we observe a most remarkable and extraordinary drop, a drop all the more surprising and convincing since the death-rate here shown is that from diseases and causes of death other than typhoid fever. This curve shows apparently even more clearly than does the typhoid fever curve itself at the top of the chart the striking effect of the purification of the public water-supply.

XIV. GRAPHICAL DEMONSTRATION AND DISCUSSION OF THE LOWELL PHENOMENA

We now present a graphical demonstration of the phenomena at Lowell, based upon statistics which have the same secure foundation as those for Lawrence.

This city, 28 miles below Manchester, and 12 miles below Nashua, N.H., both the latter cities and several others at greater distances discharging their sewage into the Merrimac River, used the polluted river water without purification until 1893. In that year deep wells were driven and the new water was introduced into the city mains along with the old. The supply of ground-water was gradually increased until 1896, when the river water was entirely shut off. The following table shows the progress of the substitution of pure water for polluted:

TABLE 8.

AVERAGE CONSUMPTION OF RIVER WATER AND OF GROUND-WATER IN LOWELL.*

Year	Total Consumption (Million Gals. per Day)	River Water (Percentage of Total)	Ground-Water (Percentage of Total)
1892	...	100	0
1893	6.8	91	9
1894	6.6	65	35
1895	7.0	33	67
1896	7.0	4	96
1897	...	0	100

* Computed from diagram in *Annual Report of Lowell Water Board, for 1896*. The first well water was pumped September 16, 1893. The river water was finally shut off February 22, 1896. Thus 1893 was essentially the last year of the old supply, and 1896 the first year of the new.

The statistics upon which we have based our studies of Lowell are presented in Tables 9 and 10.

TABLE 9.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, LOWELL, MASS., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:													
1880	†59,475												
1883	62,253	1,432	49	103	35	249	125						
1884	63,179	1,400	41	114	43	206	136						
1885	†64,107	1,329	49	85	26	196	126						
1886	66,824	1,499	50	106	33	191	165						
1887	69,542	1,869	90	168	64	232	157						
1888	72,260	1,763	62	154	61	190	183	107	34	159	102	31	50
1889	74,078	1,897	69	145	73	213	215	101	30	159	141	55	46
1890	†77,696	1,960	125	145	96	214	218	41	42	164	148	66	56
1891	79,030	1,075	78	187	96	222	251	16	44	155	156	61	66
1892	80,364	2,229	77	215	114	231	229	28	51	231	140	56	64
Years of change:													
1893	81,698	2,108	55	217	126	212	286	36	52	216	128	69	54
1894	83,032	1,790	51	137	90	188	221	36	37	146	123	51	47
1895	†84,367	1,869	33	155	78	160	218	52	59	142	154	62	62
1896	86,487	1,922	38	157	86	185	221	46	51	140	153	68	64
Ground-water:													
1897	88,607	1,860	17	170	107	180	177	40	67	133	158	46	46
1898	90,727	1,809	25	165	100	188	185	37	62	115	163	49	91
1899	92,848	1,851	18	107	75	194	179	41	63	112	156	22	54
1900	†94,969	1,850	19	208	86	181	132‡	27	77	137	190	40	73
1901	94,953	2,041	18	238	67	160	⋮	114	72	156	197	40	82
1902	94,937	1,943	17	189	80	154	⋮	73	82	172	219	34	77
1903	94,021	1,899	26	191	71	124	⋮						
1904	94,905	1,738	18	177	73	126	⋮						
1905	†94,889	1,899	17	178	70	148	⋮						

* From Massachusetts State Registration Reports, except last four columns, which are from Reports of Lowell Board of Health. Stillbirths are excluded.

† Census years. U.S. Census on the even decades; State Census at the intermediate fifth year. Other populations interpolated by the "arithmetical" method.

‡ Title discontinued in State Reports. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank.

From these figures the plots in Chart 5 have been constructed. These show the death-rates from various causes for a number of years, as for Lawrence, before and after the purification of the water-supply, including two U.S. Censuses and three state Censuses. Here, as at Lawrence, we have, therefore, a substantial basis for population statistics. The method of plotting is the same as for Hamburg and Lawrence. The gradual substitution of unpolluted for polluted water is represented by the tapering portion of the black bar. The same scale is used for all curves except the bottommost, and here again the diagrams have been cut off so that no base-lines appear.

TABLE 10.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, LOWELL, MASS., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease	Old Age	Diseases of the Kidneys
Merrimac River, unpurified:												
1883	2,300	70	165	56	400	201						
1884	2,216	65	180	68	326	215						
1885	2,073	70	133	41	306	196						
1886	2,243	75	150	49	286	247						
1887	2,688	120	242	92	334	226						
1888	2,440	86	213	84	263	253	148	47	220	141	43	60
1889	2,530	92	193	97	284	287	135	52	212	188	73	61
1890	2,523	101	187	123	276	280	53	54	211	190	85	72
1891	2,490	90	237	121	281	318	20	56	196	197	77	84
1892	2,774	96	268	142	288	285	35	64	287	174	70	80
Years of change:												
1893	2,380	67	266	154	250	350	44	64	264	157	84	66
1894	2,156	61	165	108	226	266	43	45	176	148	61	57
1895	2,215	30	184	92	190	258	62	70	168	183	73	75
1896	2,122	44	182	90	214	256	53	59	172	177	79	74
Ground-water:												
1897	2,000	19	192	121	203	200	45	76	150	178	52	52
1898	1,904	28	182	110	207	204	41	68	127	180	54	100
1899	1,904	19	212	81	209	193	44	68	121	168	24	58
1900	1,948	20	210	91	191	139	28	81	144	200	42	77
1901	2,150	19	251	71	168	‡	120	76	164	207	42	86
1902	2,047	18	190	84	162	‡	77	86	181	231	36	81
1903	2,001	27†	201	75	131	‡						
1904	1,831	19	187	77	133	‡						
1905	2,001	18	188	74	156	‡						

* Computed from preceding table.

† Epidemic August, 1903, due to check-valve accident.

‡ Title discontinued in reports.

Changed from raw river water to deep wells. First ground-water pumped September, 1893. River water finally shut off February, 1896.

Beginning with the curve for typhoid fever, we find that here, as at Lawrence, the mortality had been subsiding, as was to be expected after the epidemic proportions of 1890; but sank still lower in the years of introduction of ground-water, remaining since at a comparatively low level.

Pneumonia, which had been on the whole rising, distinctly tho irregularly for many years, exhibits the striking phenomenon of an immediate drop from the high point which it had reached in 1893. The comparatively low level to which it now descended was, moreover,

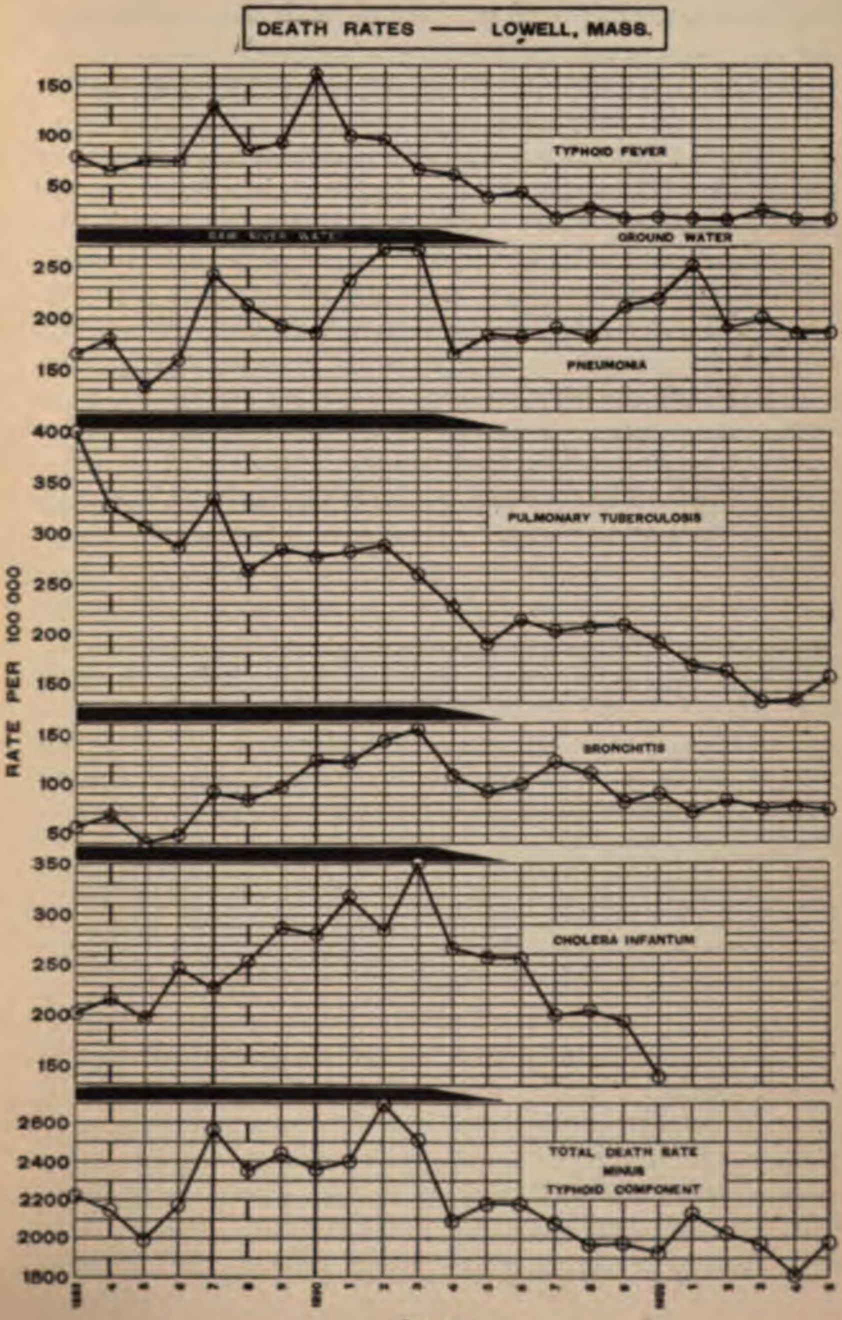

DEATH RATES —— LOWELL, MASS.
RATE PER 100 000
150
100
50
TYPHOID FEVER
RAW RIVER WATER
GROUND WATER
250
200
150
PNEUMONIA
400
350
300
250
200
150
PULMONARY TUBERCULOSIS
150
100
50
BRONCHITIS
350
300
250
200
150
CHOLERA INFANTUM
2600
2400
2200
2000
1800
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
1883
4
5
6
7
8
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5

CHART 5.

general maintained, tho with certain fluctuations, up through last year shown.

Pulmonary tuberculosis had been declining steadily prior to 1894, from the curve no influence of purification of water-supply can demonstrated, but that in this disease also the benefits of the better ter were felt is clearly indicated by the analytical study in our contribution to the volume "Tuberculosis in Massachusetts" (referred to, p. 491 above) and by later study in sec. xvi of the present paper.

Bronchitis had been rising rapidly, up to the critical years 1894 and 1895, but at this time the whole trend of the curve was reversed, a distinct fall setting in—more rapid at first, and later settling gradually to the comparatively low level maintained for the last seven years of the period.

One of the most striking effects is seen in cholera infantum, which had been on the increase for some years before introduction of groundwater, but immediately afterward showed a rapid descent. Unfortunately reliable data for 1901 ff. were not available, but these years are less important than the years immediately following purification.

Finally, we discover, as at Lawrence, in the last curve of the chart an extraordinary demonstration of the Mills-Reincke phenomenon. The total death-rate minus typhoid component, which had risen as high as 27 and had scarcely gone below the excessive rate of 24 in the seven years prior to the critical years 1894–95, now shows in 1894 the surprising drop to a level of 21, sinking in subsequent years even lower.

XV. A GRAPHICAL DEMONSTRATION OF THE PHENOMENA AT MANCHESTER, NEW HAMPSHIRE, A CITY HAVING A WATER-SUPPLY OF GOOD QUALITY.

As a control or norm with which the phenomena at Lawrence and Lowell may be compared we have taken Manchester, N.H., a city which, as we have already stated, is in all important respects closely similar to Lawrence and Lowell. This similarity may be demonstrated statistically by reference to the U.S. Census for 1890 and 1900 and the Massachusetts State Census for 1895. We have taken from those sources figures relating to age, sex, and nativity distribution, and occupations of the population, which not only demonstrate the similarity of the three cities in the respects stated but also the fact that the three censuses show no significant differences in the percentages. It is a well-known fact that the mortality rates of communities may be considerably affected by the age distribution of the population, since death-rates are much higher for the very young and the very old. The death-rates of the age-groups under five years and over forty-five years are usually higher than that of the whole population, whereas the death-rates of other ages are lower, tho the limits may vary somewhat for different cities. By reference, for instance, to the Massachusetts State Registration Report for 1895, we ascertain the death-rate for that year for the whole population to be 19.01 per 1,000; the rate for the age-group under five years, 64; for the group five–ten, 6; for succeeding age-groups up to fifty, rates less than 19; but for all groups above fifty, rates higher again than that for the whole population. Again, as is well known, general death-rates are affected to greater or less extents by distribution according to sex, place of birth, and occupations of the population. We therefore present without further comment the following table:

TABLE 11.*

RATIOS OF:	PERCENTAGES							
	LAWRENCE			LOWELL			MANCHESTER	
	1890	1895	1900	1890	1895	1900	1890	1900
Age-groups under five and over forty-five to total population	28.0	28.2	28.6	27.4	27.0	28.4	27.2	29.1
Male population to total population	46.6	48.2	48.3	45.6	46.1	47.3	45.0	46.7
Persons born in Canada (English) to total population	10.0†	2.0	2.7	20.3†	1.9	4.7	28.1†	3.0
Persons born in Canada (French) to total population		8.9	11.2		15.2	15.4		23.6
Persons born in Great Britain‡ to total population	13.7	12.9	10.2	6.6	6.7	5.9	3.5	3.1
Persons born in Germany to total population	4.1	4.6	3.9	0.2	0.2	0.2	2.0	2.0
Persons born in Ireland to total population	17.2	14.4	11.3	16.3	14.9	12.8	9.8	7.4
Persons born in other countries to total population	0.9	3.8	6.4	1.1	5.3	4.1	2.1	3.5
Total foreign-born	45.9	46.6	45.7	44.5	44.2	43.1	45.5	42.6
Wage-earners to total population	34.9	....	35.7	35.7	....	33.0	34.8	33.4
Textile operatives¶ to total wage-earners	68.9	....	76.1	63.7	....	65.0	62.2	58.7

* Computed from U.S. Censuses, 1890 and 1900, and Massachusetts Census, 1895.

† Canada and Newfoundland.

‡ England, Scotland, and Wales.

¶ Workers in manufacture of cotton, woolen, knit, and worsted goods, and hosiery.

Thus the above statistics confirm and supplement the knowledge ed by the personal familiarity of the authors with these three s that they are in all important respects closely similar.

The statistics upon which we have based our studies of Manchester presented in Tables 12 and 13.

TABLE 12.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup¶	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
Same water-supply, of good quality, throughout:													
1880	‡32,630												
1883¶	35,220	760	20	54	7	116	131						
1884	37,230	764	17	46	18	117	112						
1885	38,380	783	22	55	20	107	88						
1886	39,530	748	15	33	9	118	122						
1887	40,680	814	18	51	31	90	148						
1888	41,830	869	14	55	37	115	117	55	11	31	46	24	5
1889	42,980	778	18	53	35	78	86	49	18	22	47	18	12
1890	‡44,126	973	15	83	40	106	146	28	18	36	43	27	22
1891	45,410	805	19	85	38	98	122	9	15	24	42	18	17
1892	46,700	980	5	50	38	91	102	11	21	20	56	20	24
1893	47,980	1,013	14	66	43	91	86	7	23	21	44	28	13
1894	49,270	1,001	23	86	59	92	138	37	15	38	55	13	13
1895	50,560	1,036	21	107	55	83	144	26	19	47	80	22	16
1896	51,840	1,064	19	90	54	126	115	45	17	29	77	21	21
1897	53,130	1,140	12	119	88	111	123	38	29	39	70	18	22
1898	54,410	1,003	14	89	47	88	136	26	26	33	53	15	31
1899	55,700	1,061	11	134	65	101	92	13	31	61	69	21	31
1900	‡56,987	1,153	9	120	39	117	148	13	34	56	84	21	30
1901	58,270	1,143	9	115	37	104	132	8	27	35	88	13	36
1902	59,560	1,088	8	121	55	78	§	30	38	§	72	20	28
1903	60,850	1,112	9	112	41	79	§						
1904	62,130	1,015	12	101	31	87	§						
1905	63,420	1,339	11	129	22	108	§						

---

* From N.H. State Registration Reports, except last four columns, which were kindly furnished by Dr. Irving A. Watson, State Registrar of Vital Statistics, N.H. For certain of the less important causes only the period 1888–1902 inclusive has been included, the spaces for the remaining years being left blank. Stillbirths are excluded.

† Including angina pectoris, embolism, and phlebitis.

‡ U.S. Census years. Intermediate populations interpolated by the "arithmetical" method.

¶ Year ending March 31, 1883.

§ Change of classification.

From these death-rates we have constructed the diagrams in Chart 6, using the same method of plotting as for Hamburg. Lawrence, and Lowell. As Manchester had a water-supply of good quality throughout, there are no black bars.

Typhoid fever remained at a fairly low level throughout the period, and this was to be expected from the character of the water-supply. This curve therefore affords a valuable background for viewing the typhoid fever death-rates of the other two cities.

TABLE 13.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, MANCHESTER, N.H., 1883 TO 1905 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Pneumonia	Bronchitis	Pulmonary Tuberculosis	Cholera Infantum	Diphtheria and Croup	Apoplexy	Inanition, Marasmus, and Infantile Debility	Heart Disease†	Old Age	Nephritis, incl. Bright's Disease
1883	‡2,158	57	153	20	329	372						
1884	2,052	46	124	48	314	301						
1885	2,040	57	143	52	279	229						
1886	1,892	38	84	23	290	309						
1887	2,001	44	125	76	221	364						
1888	2,077	33	132	88	275	280	132	26	74	110	57	22
1889	1,810	42	123	81	181	200	114	42	51	109	42	28
1890	2,205	34	188	91	240	331	63	41	82	97	61	50
1891	1,971	42	187	84	216	269	30	33	53	93	40	37
1892	2,090	11	107	81	195	219	24	45	43	120	43	51
1893	2,111	29	138	90	190	179	15	48	44	92	58	27
1894	2,032	47	175	120	187	280	75	30	77	112	26	26
1895	2,049	42	212	109	164	285	51	38	93	158	44	32
1896	2,052	37	174	104	243	222	87	33	56	140	41	41
1897	2,146	23	224	166	209	232	72	55	73	132	34	41
1898	1,842	26	164	86	162	250	48	48	61	97	28	57
1899	1,905	20	240	117	181	165	23	56	109	124	38	56
1900	2,023	16	210	68	205	260	23	60	98	147	37	53
1901	1,962	15	197	64	170	227	14	46	60	151	22	62
1902	1,827	13	203	92	131	...	50	64	...	121	34	47
1903	1,827	15	184	67	130	...						
1904	1,634	19	163	50	140	...						
1905	2,111	17	204	35	170	...						

* Computed from preceding table.

† Including angina pectoris, embolism, and phlebitis.

‡ Year ending March 31, 1883.

Same surface water-supply, of good quality, throughout.

Pneumonia was rising steadily tho irregularly until 1899, and at the very time (1894) when Lawrence experienced an extraordinary drop in pneumonia and Lowell one nearly as great, the rate for Manchester had risen higher than it had ever been before in the period considered; and then while the rates at Lawrence and Lowell remained at the level to which they had fallen, that at Manchester, on the whole, rose.

For pulmonary tuberculosis the Manchester curve, like those for the other two cities, was throughout the period falling gradually, but its rate of fall was in comparison not so rapid, the years 1896 and 1897 even showing a marked rise.

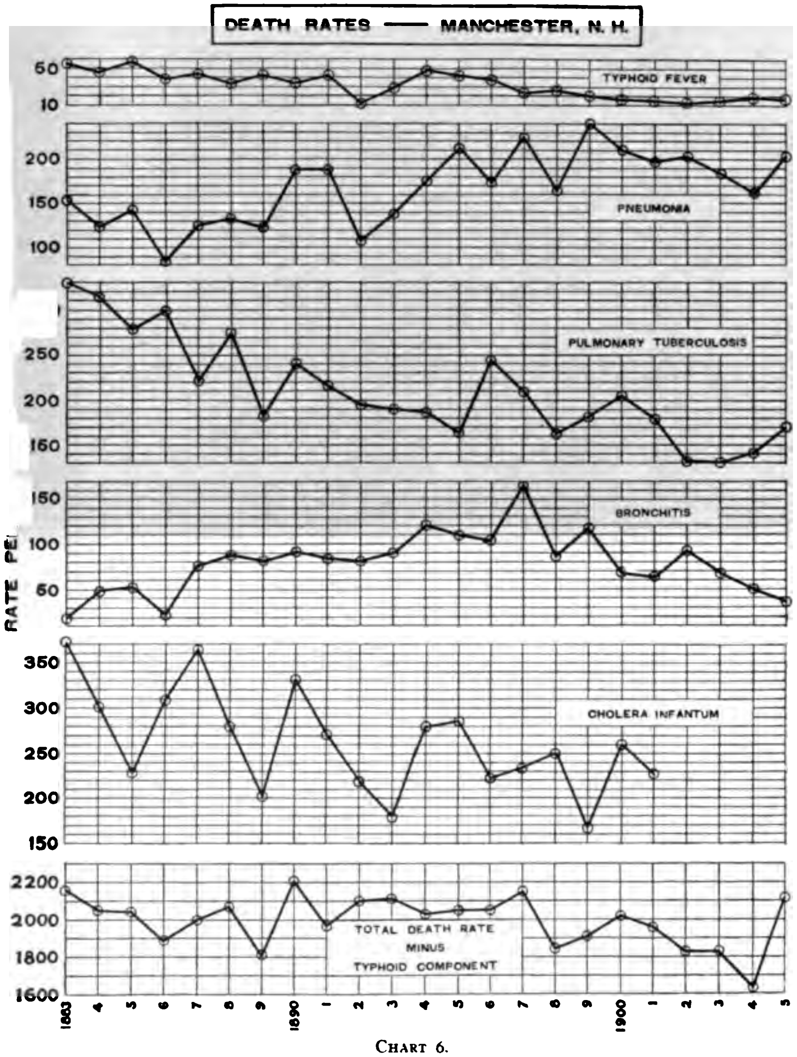


CHART 6.

Bronchitis, like pneumonia, was rising at Manchester until 1897, while at Lowell there was a decline in this disease following the introduction of ground-water. At Lawrence the decrease in bronchitis had already set in before filtration, hence without the further detailed studies which we present in sec. xvi, the fact that Lawrence experienced a greater decline than the norm cannot be readily seen.

In cholera infantum the curve for Manchester is highly irregular, but in the years 1894 and 1895, when that disease had dropped markedly in the other two cities, the rate for Manchester had risen to a maximum.

In the curve for total death-rate minus typhoid component Manchester shows a close adherence to a level of about 2,000 from 1892 to 1897, thus covering the period when Lawrence and Lowell changed their water-supplies and experienced remarkable drops in that death-rate, which had in these two cities been at a much higher level.

We shall not pause here any longer to discuss Lawrence and Lowell as compared with Manchester, reserving for sec. xvi the detailed study of the comparative relations among these three cities.

XVI. A COMPARATIVE STUDY OF THE DATA DERIVED FROM LAWRENCE, LOWELL, AND MANCHESTER.

We have seen in secs. xiii, xiv, and xv that both at Lawrence and at Lowell there followed immediately upon purification of the water-supply a lasting drop in the total death-rate—a drop much greater than could be accounted for by the decrease in typhoid fever alone; while the total death-rate at Manchester showed no such change, but kept steadily on the same comparatively low level.

The drops at Lawrence and Lowell we shall examine somewhat more closely in order to determine: (1) the extent of the reductions in their total death-rates in comparison with the norm, Manchester; and (2) what causes of death played the principal parts in these reductions. Throughout we shall compare Lawrence and Lowell with each other and with the norm, Manchester.

In the analysis of the declines we have first taken seven chief causes of death, omitting "accident," as given in the tables of the Massachusetts State Registration Report for 1890. These are: phthisis, causing in that year 5,791 deaths; pneumonia, 4,038; cholera infantum, 2,491; diphtheria and croup, 1,626; bronchitis, 1,533; apoplexy, 1,301; and typhoid fever, 835; making a total of 17,615 deaths. The total number of deaths in Massachusetts for the year was 43,528. In addition to this list we have taken several important general headings given in most nosological arrangements, in order to include diseases of all the general classes, viz.: inanition, marasmus, and infantile debility; heart disease; old age; and diseases of the kidneys. The sum of all titles above mentioned formed 50 to 60 per cent of the total deaths in Manchester, Lowell, and Lawrence, and if causes of death other than disease be omitted, the percentage is somewhat higher.

It may be objected that a few of these titles, e.g., old age, are too vague to serve in an accurate analysis, and the objection is valid so far as exact and absolute determinations of mortality are concerned. For purposes of comparison of the rates in the same city at periods not much separated, however, the indefiniteness of any given title does not greatly affect its value in the analysis. The limits covered by any title depend upon the local usage of the medical profession in the community in question; and as such usage commonly changes only gradually, year to year comparisons are not seriously interfered with. The important phenomena considered in this paper are *sudden* decreases in death-rates taking place within a short space of time.

Mortality statistics for the various causes of death, illustrating the phenomena at Lawrence and Lowell, as compared with the norm, Manchester, before and after water-supply purification, are given in Tables 14 and 15. By the use of averages for periods of five years before and after, a safer if less striking view of the facts is obtained.

From the first of these tables have been plotted Charts 7 and 8, which largely explain themselves. It must be observed that the periods of five years each, before and after water-supply purification, do not quite correspond for Lawrence and Lowell, so that the corresponding Manchester blocks in the upper and lower halves of the chart do not represent exactly the same periods for that city.

These diagrams demonstrate certain points which do not clearly appear in the curves in Charts 4 and 5, one of the chief advantages being that the movements of the rates in Manchester, the norm, are readily seen in direct comparison with those in the other two cities. Thus, for example, the stationary bronchitis rate at Lawrence is seen to be actually a gain because that at Manchester increased; a point which does not appear in the Lawrence curve alone.

In order that the actual extent of the decreases in death-rates may be determined, reckoned against the corresponding changes at Manchester, as well as independently, we have also made the computations presented in Table 16.

TABLE 14.

MORTALITY RATES FROM CERTAIN DISEASES IN LAWRENCE, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of filtration at Lawrence.

	LAWRENCE		MANCHESTER	
	1888–1892 (Before)	1894–1898 (After)	1888–1892 (Same Periods as for Lawrence)	1894–1898
Typhoid fever	110	32	32	35
Pneumonia	255	202	148	190
Bronchitis	49	47	85	117
Pulmonary tuberculosis	244	185	222	192
Cholera infantum	222	201	260	254
Diphtheria and croup	152*	59	71	67
Apoplexy	55	62	37	41
Inanition, marasmus, and infantile debility	146	100	61	72
Heart disease	126	110	106	130
Old age	42	37	49	35
Diseases of the kidneys	36	36	36	30
Total death-rate	2,494	1,998	2,032	2,024

* Epidemic in 1889, when the rate rose to 391.

TABLE 15.

MORTALITY RATES FROM CERTAIN DISEASES IN LOWELL, MASS. (AS COMPARED WITH MANCHESTER, N.H.), BEFORE AND AFTER WATER-SUPPLY PURIFICATION.

Mean annual death-rates (per 100,000) for five-year periods just before, and just after, introduction of ground-water at Lowell.

	LOWELL		MANCHESTER	
	1889–1893 (Before)	1896–1900 (After)	1889–1893 (Same Periods as for Lowell)	1896–1900
Typhoid fever	103	26	32	24
Pneumonia	230	197	149	202
Bronchitis	127	100	85	108
Pulmonary tuberculosis	278	205	205	200
Cholera infantum	304	198	240	226
Diphtheria and croup	57	42	47	51
Apoplexy	58	70	42	50
Inanition, marasmus, and infantile debility	234	143	55	70
Heart disease	181	181	102	130
Old age	78	50	49	36
Diseases of the kidneys	73	72	30	90
Total death-rate	2,581	2,051	2,059	1,994

From these figures it is seen that when the decreases in Manchester are taken into account, and subtracted algebraically with the proper signs, as normal, from those in the other two cities, the declines in certain diseases in the latter cities stand out from the obscurity

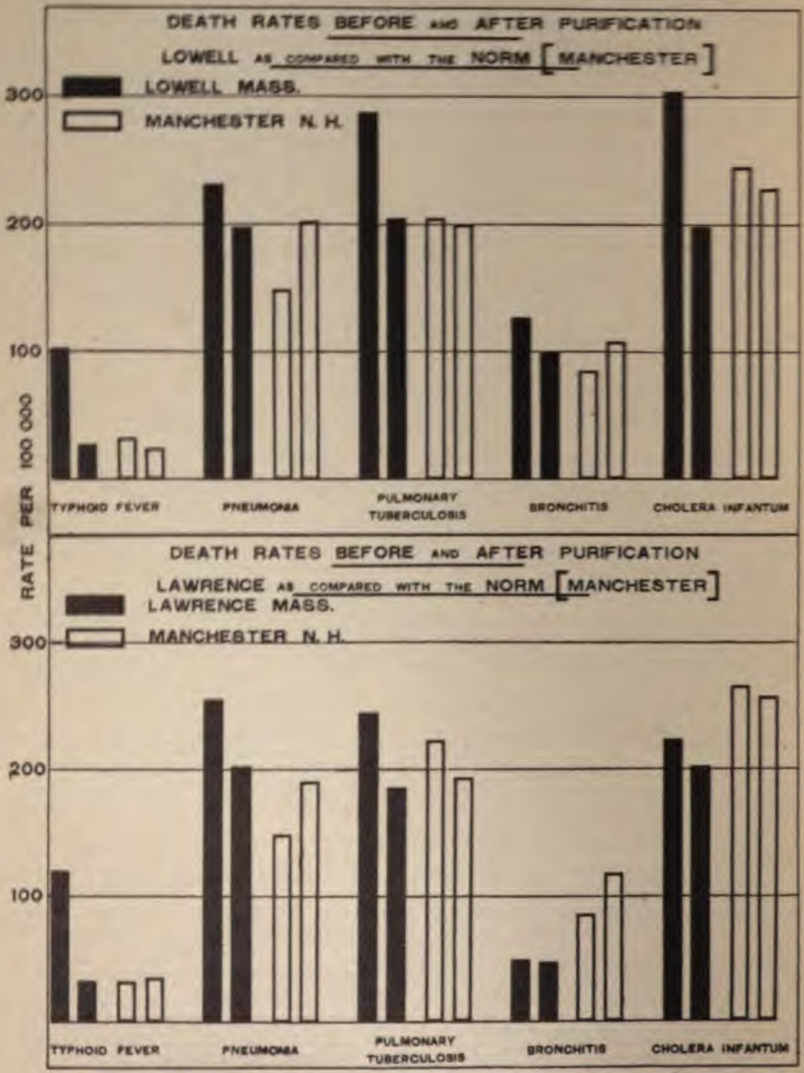


Chart 7.

in which they are masked when only the actual decreases are considered. Chief among these diseases are pneumonia and bronchitis.

Taking up first typhoid fever, and referring to Chart 7 as well as to the tables just given, we find that the rates at Manchester from that disease show the good and unvarying quality of the water-supply there, thus demonstrating the city's normality in that respect. The great drops at the other two cities following water-supply purification stand out clearly.

TABLE 16.

DECREASES IN DEATH-RATES FROM CERTAIN CAUSES IN LAWRENCE AND LOWELL FOLLOWING WATER-SUPPLY PURIFICATION.

Rates are per 100,000 population.

CAUSES OF DEATH	DECREASES IN DEATH-RATES							
	APPARENT (COMPUTED DIRECTLY)				TRUE (SUBTRACTING ALGEBRAIC DECREASE AT MANCHESTER AS NORMAL)			
	LAWRENCE		LOWELL		LAWRENCE		LOWELL	
	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease	Decrease	Percentage of Total Decrease
Typhoid fever	87	18	77	15	90	18.5	69	14
Pneumonia	53	11	33	6	95	19.5	86	18
Bronchitis	2	0	27	5	34	7	50	10
Pulmonary tuberculosis	59	12	73	14	30	6	68	14
Cholera infantum	21	4	106	20	15	3	92	19
Diphtheria and croup	93	19	15	3	89	18	19	4
Inanition, marasmus, and infantile debility	46	9	91	17	57	12	115	24
Old age	5	1	28	5	−9	−2	15	3
Other causes	130	26	80	15	87	18	−29	−6
All causes	496	100	530	100	488	100	485	100

In respect to pneumonia, while Manchester rose markedly from 148 to 190, Lawrence dropped from the high rate of 255 to the normal of 202. Lowell shows a similar decrease. In both cases the closeness of the rates, after improvement, to those of Manchester is additional evidence for the conclusion that the polluted water had caused an abnormally high rate, which declined at once, on the removal of the pollution, to the normal level.

Pulmonary tuberculosis was decreasing in Massachusetts and New Hampshire during the period 1890–1900. The diminution for the state of Massachusetts—shared fully, as detailed study shows, by cities of the same class as Lawrence and Lowell—is indicated by the following rates per 100,000 from the state registration: for 1890, 259; for 1895, 219; and for 1900, 185. Similarly in New Hampshire the rates were: for 1890, 219; for 1895, 177; and for 1900, 158. In a comparison of Manchester and Lawrence, both cities show a decrease, but that in Manchester is comparatively small. The decrease in the latter is what might be expected from general improvement in sanitary conditions. Lawrence starting higher came down to about the level of the norm. Lowell shows the same phenomenon as compared with Manchester, but in much more marked degree. In actual figures Lawrence shows a decrease 30 greater than the normal, and Lowell, 68 greater. These facts, in spite of many complicating factors, indicate a certain amount of decrease due to the change in water-supply. Phthisis being a disease of slow development and often long-postponed fatality, an effect on the mortality could hardly be expected to appear immediately after an improvement in one condition favoring its spread or fatality; and where many such conditions are involved the effect might well be somewhat obscured. We wish therefore to emphasize particularly the evidence here given that both at Lawrence and at Lowell there were decreases in pulmonary tuberculosis following water-supply purification considerably greater than the corresponding normal decreases at Manchester, as this point is not distinctly demonstrable by the curves for the former cities alone.

Bronchitis, which includes both chronic and acute disease, shows much the same phenomena as does pneumonia. At Manchester the rate rose distinctly; at Lawrence, however, it did not rise, but remained stationary; while at Lowell there was actually a decrease amounting to 50 more than the normal decrease. This also is a case of improvement which is much better demonstrated by the blocks of Chart 7 than by the curves.

Cholera infantum, a general title indicative of intestinal diseases of infants, shows a decrease in all three cities. In Lawrence, however, there was a decrease of 15 more than the normal, while Lowell shows a remarkable corresponding surplus decrease of 92. The latter stands out as one of the most striking phenomena observed, and recalls with emphasis Dr. Reincke's statement that the mixing of raw river water with milk caused much of the infant mortality at Hamburg (pp. 497, 500, 502, above). The same explanation probably also holds good to a very great extent for Lawrence and Lowell.

Among the minor causes of death not plotted in the charts, tho included in the tables, we consider first inanition, marasmus, and infantile debility, a heterogeneous and indefinite title, but one fairly indicative of the mortality of the feeble. Infantile debility makes up a large part of it, and probably a considerable number of deaths from diarrhea and the gastro-intestinal diseases of infants are here included through false diagnosis. As seen from the tables, both at Lawrence and at Lowell the mortality shows a great decrease, while at Manchester a considerable rise took place. On account of the tendency in diagnosis just mentioned it well may be that much of the effect of water-supply purification at Lawrence upon infant mortality is indicated by this title, the cholera infantum rate not having been much lowered.

For old age the figures indicate a slight rise at Lawrence, but at Lowell a decrease distinctly greater than the normal.

Heart disease (uncertain in diagnosis) shows improvements greater than the normal by about 30.

In diseases of the kidneys and apoplexy there are no phenomena worthy of mention.

With reference to diphtheria and croup the mixt character of the title, the highly epidemic character of diphtheria, and the use of antitoxin complicate matters so much that we can draw no conclusions from the figures.

The Mills-Reincke phenomenon at both Lawrence and Lowell is shown very strikingly by Chart 8. (We must caution the reader, that in order to save space the blocks in this chart have been cut off so that their true bases do not appear.) Here the drops seen in the curves in Charts 4 and 5 are reduced to actual quantitative statement for five-year periods just before and after water-supply purification. At Lawrence the total death-rate minus typhoid component dropped from 23.7 to 19.7 per 1,000 with an annual saving of about 200 lives from causes other than typhoid fever. At Lowell it dropped from 24.8 to 20.3, with a saving of 365 lives from such causes. Manchester, on the other hand, shows decreases for the corresponding periods of only 0.1 and 0.4 respectively. In other words, the

REDUCTION IN DEATH RATE
FROM
DISEASES OTHER THAN TYPHOID FEVER
FOLLOWING
WATER SUPPLY PURIFICATION

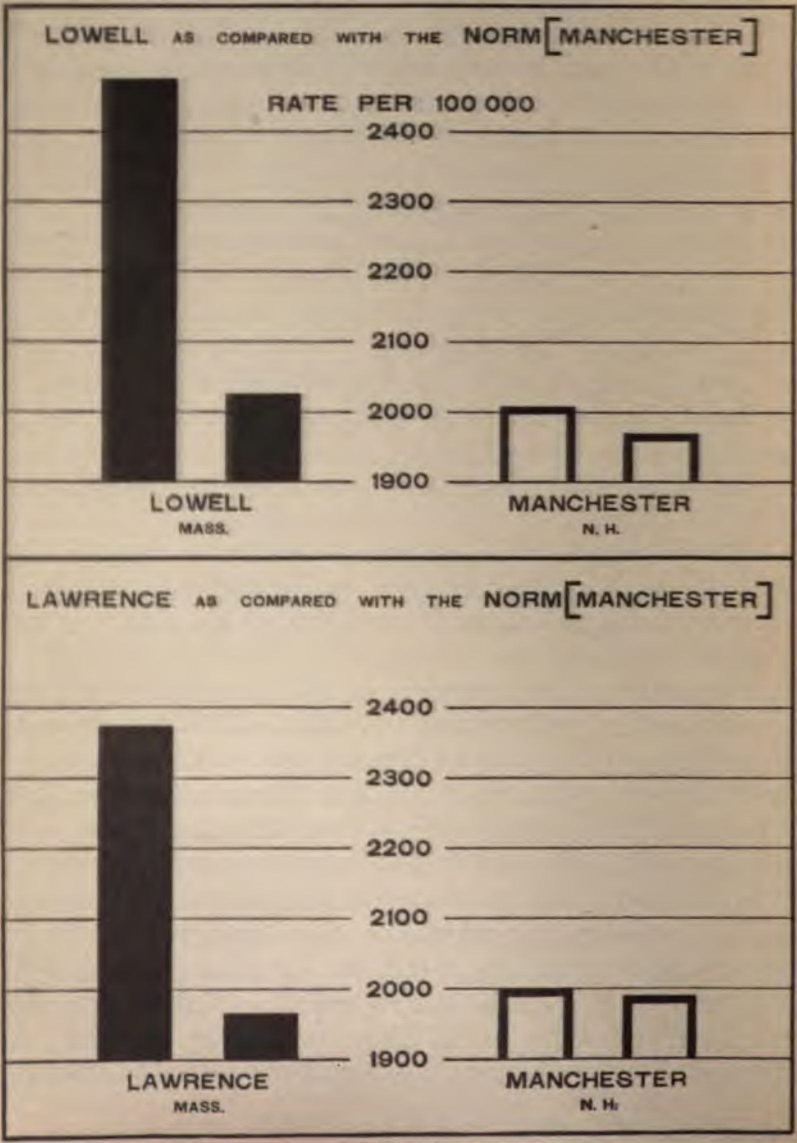


CHART 8.

first two cities, which had used polluted and unpurified water-supplies and had had very excessive "total minus typhoid" death-rates, dropped after purification to the normal and comparatively low rate level (*ca.* 20.0) which Manchester had maintained throughout.

The second of the two questions proposed at the outset of this section, i.e., what causes of death played the principal parts in the reductions in the total death-rates, is also answered in Table 16 above, by the percentage columns. If the rates for Lawrence and Lowell be averaged, over 80 per cent of the decreases in total death-rates—whether actual or comparative (against Manchester) rates be considered—are accounted for. In this decrease, the chief parts were played (besides typhoid fever) by pneumonia, pulmonary tuberculosis, cholera infantum, and inanition, marasmus, and infantile debility. Cholera infantum and the last three causes of death are, as we have already stated, somewhat related by diagnosis. And these results agree with those already obtained for Hamburg (secs. iv and v).

The foregoing analysis affords a basis for a testing of Hazen's theorem. As a preliminary computation we find that at Lawrence, for every death less from typhoid fever there were 4.7 deaths fewer from other causes, and at Lowell 5.9 fewer. These, however, are only crude ratios which include any rises or falls of the rates which would have taken place in any event independent of water-supply purification. It is therefore necessary, in order to obtain ratios comparable with that suggested by Mr. Hazen (which was based upon computations from which decreases due to causes other than water-supply purification had been approximately eliminated), to consider the decreases *minus* those at Manchester as normal. We compute, therefore, from Table 16, that—

> Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths [*4.4 at Lawrence and 6.0 at Lowell*] from other causes have been avoided.

Thus Mr. Hazen's estimate of two or three is seen to have been for these cities very conservative.

At this point we may briefly consider certain objections which may perhaps be raised against the accuracy of the foregoing statistical studies or our interpretation of them. We have already shown (sec.

iv) that for three census years (1890, 1895, and 1900) the age and sex ributions, the proportions of foreign-born of various nationalities, and the occupations of the population at Lawrence and Lowell were practically the same. Between census years there were undoubtedly fluctuations in these conditions, but any such could have been only temporary, as otherwise they would be indicated by the census figures. Of fluctuations in the actual number of the total population as related to population estimates we have made a special study, the results of which are submitted in sec. xviii. Anticipating, we may state here our conclusion that no error seriously affecting our results has been introduced from that direction. Moreover, important fluctuations in quality or quantity of population at Lawrence and Lowell should have had a counterpart at Manchester, a city in all essential respects similar, with which comparisons have throughout been made. The same remark applies also to mortality decreases due to general sanitary and medical improvement (upon which, it will be remembered, Dr. Reincke laid considerable stress in the case of Hamburg).

Such *sudden* and *lasting* decreases in death-rates as took place in each of these cities can be explained only by sudden and permanent measures of sanitation, and it is impossible to escape the conclusion that the principal part in the drop in total death-rate—the Mills-Reincke phenomenon—both at Lawrence and at Lowell, was played by the purification of the public water-supply.

XVII. STUDIES OF SIMILAR PHENOMENA IN SOME OTHER AMERICAN CITIES

1. *Albany, N.Y.* — As another example of the Mills-Reincke phenomenon occurring in a prominent city which has purified its public water-supply and for which reliable vital statistics are obtainable, we present Albany, N.Y.

Previous to 1899 two-thirds of the total water-supply of this city was taken from the Hudson River without purification, while the remaining third came by gravity from watersheds just west of the city. In September, 1899, slow sand filtration of the Hudson River supply was introduced, while the surface water-supply remained unchanged. The statistics upon which we have based our demonstration of the Albany phenomena are given in the following Tables 17 and 18.

The death-rates for Albany are plotted on Chart 9, in which the same methods of presentation are employed as for Hamburg, Lawrence, and Lowell.

TABLE 17.

TOTAL DEATHS, DEATHS FROM CERTAIN DISEASES, AND POPULATION, ALBANY, N.Y., 1885–1907 INCLUSIVE.*

Year	Population	Total Deaths	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:							
1880	†90,758						
1885	92,841	1,993	49	182	290	101	685
1886	93,257	‡2,005	‡79	‡255	‡302	‡117	‡667
1887	93,674	2,020	71	203	337	121	561
1888	94,090	2,332	74	283	312	137	773
1889	94,507	2,262	77	297	294	81	741
1890	†94,923	2,265	62	386	327	124	641
1891	94,846	2,383	108	421	310	150	632
1892	94,769	2,558	50	448	298	165	863
1893	94,692	2,140	58	381	257	103	578
1894	94,615	2,162	52	326	301	118	656
1895	94,538	2,345	162	311	287	147	607
1896	94,461	2,090	97	244	298	126	556
1897	94,384	2,013	84	312	259	107	490
1898	94,307	1,904	94	225	238	88	464
1899	94,230	1,991	82	263	248	72	510
After filtration:							
1900	†94,151	1,742	38	256	231	70	382
1901	94,996	1,751	20	220	239	42	298
1902	95,841	1,623	29	227	215	37	251
1903	96,686	1,808	19	242	228	39	321
1904	97,531	1,848	18	258	216	§	281
1905	¶98,374	1,813	19	227	212	§	329
1906	99,219	1,770	20	§	193	§	322
1907	100,064	1,900	20	§	177	§	313

* From Reports of the N.Y. State Dept. of Health.

† U.S. Census. ¶ State Census. Other populations interpolated by the "arithmetical" method.

‡ Eleven months only, December not being given.

§ Title discontinued in reports.

Typhoid fever, which had been excessively prevalent, dropped immediately after the introduction of filtration to a much lower level. In addition to this there took place a decrease in the total death-rate minus the typhoid component, Albany thus furnishing another illustration of the Mills-Reincke phenomenon. This fact was noticed and reported by Mr. Mills and others, before our work began.

The decreases in the mortality from certain diseases at Albany are somewhat different in degree from those observed at Lawrence, Lowell, and Hamburg. Altho the death-rates at Albany from acute respiratory diseases, pulmonary tuberculosis, and "diarrheal diseases" (not including typhoid fever) were lower after the introduction of filtration than before, it must be noted that all three rates had been declining before that time, and that in none of them does there appear any ater rapidity of decline setting in at this time. The most noticeable result shown by any curve of chart (except that for oid fever) appears in the death-rate under five years of age, r which the rate of decline just subsequent to 1899 was somewhat greater than it had been before. Falling to about 300, it continued

TABLE 18.

TOTAL DEATH-RATES, AND DEATH-RATES FROM CERTAIN DISEASES, ALBANY, N.Y., 1885 TO 1907 INCLUSIVE, PER 100,000 OF POPULATION.*

Year	Total Death-Rate	Typhoid Fever	Acute Respiratory Diseases	Pulmonary Tuberculosis	Diarrheal Diseases	Deaths under Five Years of Age
Before filtration:						
1885	2,147	53	196	322	109	738
1886	†2,150	†85	†274	†324	†126	†716
1887	2,157	76	217	360	129	599
1888	2,478	79	301	332	146	821
1889	2,303	81	314	312	86	784
1890	2,386	65	407	345	131	675
1891	2,512	114	444	327	158	667
1892	2,609	53	472	315	174	911
1893	2,260	61	402	271	109	610
1894	2,285	55	345	318	125	694
1895	2,480	171	329	304	156	738
1896	2,222	103	259	316	134	589
1897	2,133	89	331	274	114	519
1898	2,019	100	239	252	93	492
1899	2,113	87	279	263	76	542
After filtration:						
1900	1,850	40	272	246	74	406
1901	1,843	21	232	252	44	314
1902	1,603	30	237	224	39	262
1903	1,870	20	250	236	40	332
1904	1,805	18	265	222	‡	288
1905	1,843	19	231	216	‡	334
1906	1,783	20	‡	194	‡	325
1907	1,800	20	‡	177	‡	313

* Computed from preceding table. Slow sand filter since September, 1899, for Hudson River water, which furnishes about two thirds of total supply. One-third of supply, both previous and subsequent to introduction of filtration, has been composed of impounded surface water.

† Eleven months only.

‡ Title discontinued in reports.

at that level up through the last year we have taken, 1907. This phenomenon is not, however, clearly reflected in the curve for total death-rate minus typhoid component, which shows no greater rapidity of decline after introduction of filtration. But even the fact that the decline in total death-rate continued as rapid as before may be in part due to the improvement of the water-supply, for it might perhaps otherwise have risen. The effect, nevertheless, is not nearly so clear-cut as in the cases of Hamburg, Lawrence, and Lowell, and requires explanation. Such explanation we believe

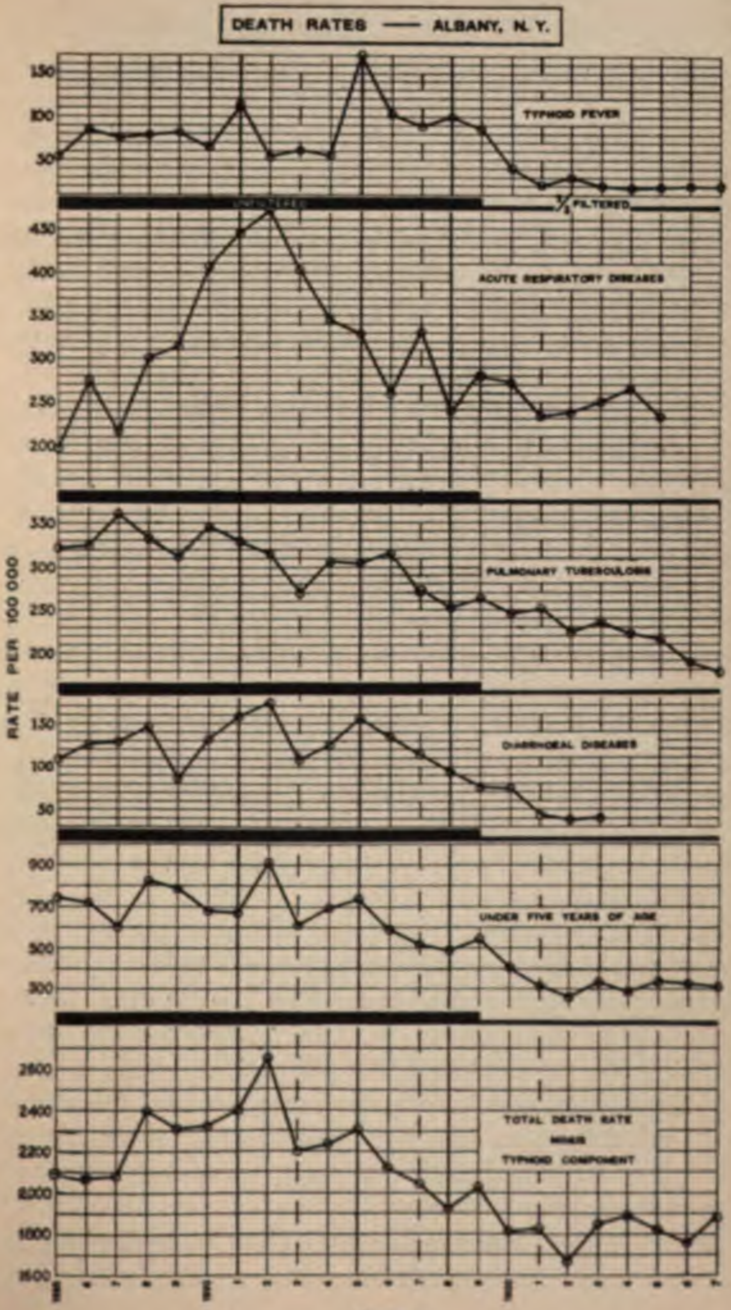

DEATH RATES — ALBANY, N. Y.
TYPHOID FEVER
150
100
50
UNFILTERED
⅔ FILTERED
ACUTE RESPIRATORY DISEASES
450
400
350
300
250
200
PULMONARY TUBERCULOSIS
350
300
250
200
RATE PER 100 000
DIARRHOEAL DISEASES
150
100
50
UNDER FIVE YEARS OF AGE
900
700
500
300
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
2600
2400
2200
2000
1800
1600

CHART 11.

may possibly be found in the fact that one-third of the water-supply has come, and still comes, without purification, from the surface sources mentioned, the quality of which is said to be somewhat uncertain. It is possible at any rate that if the whole of a supply be not purified, the resultant drop in total death-rate minus typhoid component may be much less, even tho there be, as in this case, a decided diminution in typhoid fever. We greatly regret that we have had no such personal familiarity with conditions at Albany as we have enjoyed with the various cities on the Merrimac River, and that we must leave to others possessing fuller acquaintance with local conditions the task of clearing up local difficulties.

From average death-rates for periods of five years before and after the introduction of filtration (omitting the year 1899 itself), we compute that for every death less from typhoid fever after that date, there were still, even here, 4.1 fewer from other causes. This ratio is of course uncorrected for diminutions in mortality due to other factors than filtration, so that, tho affording an approximate indication, it cannot strictly be substituted in Hazen's theorem.

2. *Binghamton, N.Y.* — Among other examples of the Mills-Reincke phenomenon which have come to our attention, we may include Binghamton, N.Y., altho this city exhibits great irregularities which distinguish it from the examples we have already discussed. Binghamton took its water-supply without purification from the Susquehanna River until June, 1902, when mechanical filtration was introduced. Certain vital statistics for this city are given in Table 19.

From these figures our Chart 10 has been constructed. It will be observed that, following the introduction of filtration, the typhoid fever death-rate, which had been excessive, tho irregular, fell to a low level and remained there. The total death-rate minus typhoid component reflected this fall, altho one year, 1904, shows a rate higher, with the exception of only two previous years, than any rate since at least 1885. This irregularity shows that this is not altogether a clear case of the Mills-Reincke phenomenon, and therefore requires for a complete solution further elucidation.

Altho the authors have been unable to give to the case any local study such as it imperatively demands, certain facts deserve mention. In the first place, both curves had before filtration shown very great irregularities, that for total death-rates minus typhoid component in particular having at one time fluctuated from 13 to 20 inside of four years. Typhoid fever had in certain years receded to a comparatively low rate, and the same is true of the total death-rate. When we consider, also, the small numbers with which we have to deal and the consequent unsteadiness of the statistics, it becomes evident that, in the absence of more detailed and thorough local studies, too much reliance should not be placed upon them.

TABLE 19.

VITAL STATISTICS OF BINGHAMTON, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:					
1880	†17,317				
1886	27,029	3	11	333	11.9
1887	29,698	14	47	433	14.6
1888	31,467	32	102	493	15.7
1889	33,236	34	102	465	14.0
1890	†35,005	21	60	545	15.6
1891	35,469	32	90	668	18.8
1892	35,933	18	50	667	18.6
1893	36,397	16	44	622	17.1
1894	36,861	18	49	584	15.8
1895	37,325	13	35	540	14.5
1896	37,789	9	24	494	13.1
1897	38,253	13	34	498	13.0
1898	38,717	28	72	584	15.1
1899	39,181	10	26	681	17.4
1900	†39,647	17	43	822	20.7
1901	40,125	21	52	755	18.8
1902	40,603	11	27	725	17.9
After:					
1903	41,081	4	10	619	15.1
1904	41,559	4	10	762	18.3
1905	‡42,036	5	12	678	16.1
1906	42,514	5	12	678	15.9
1907	42,992	8	19	673	15.6

* Compiled and computed from Reports of N.Y. State Dept. of Health.

† U.S. Census ‡ State Census. Other population figures interpolated by the "arithmetical" method. Mechanical filter since June, 1902.

On going through the Annual Reports of the New York State Board of Health in an endeavor to discover, if possible, the specific reason or reasons for the peak in total death-rate minus typhoid component in 1904, we have found that there did indeed occur in that year in Binghamton epidemics of measles and diphtheria and an unusual number of deaths from phthisis. These, however, explain only one-third of the excess of the rate for this year over the average rate for the following three years. In short, we have been unable to arrive at a satisfactory explanation of the irregularity of the total death-rate curve since 1902. We have nevertheless included Binghamton in

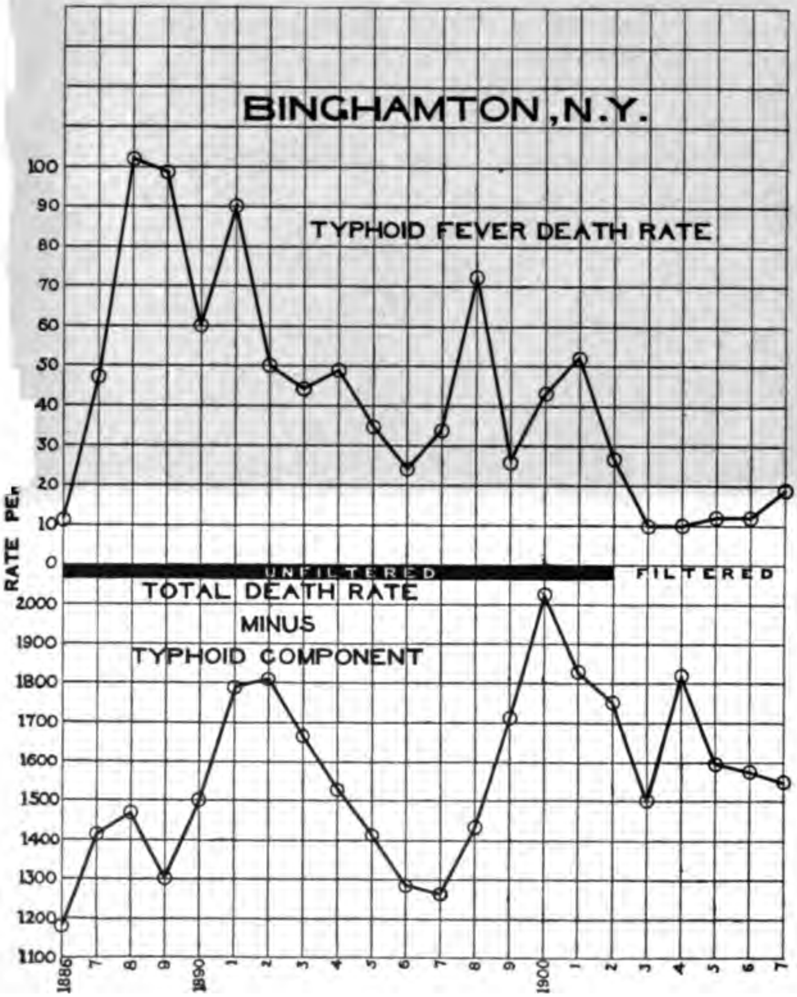


CHART 10.

our studies as an example, tho not a very clear one, of the Mills-Alth phenomenon.

study suc periods of five years before and after filtration, we compute that for one death less from typhoid fever afterward there were 1.5 fewer from other causes—this being merely an uncorrected ratio not applicable directly as a test of Hazen's theorem.

3. *Watertown, N.Y.*—As a city which had suffered severely from typhoid fever and which, after a noted epidemic in 1904, had installed a mechanical filter plant, we were led to study *in absentia* Watertown, N.Y. In the foregoing section we have presented an atypical instance of the Mills-Reincke phenomenon, and we now submit a demonstration of a city where that phenomenon did not apparently occur at all after the filtration of the public water-supply.

Until 1904 Watertown took its water from the Black River, a stream polluted by the populations of a number of towns above. In September, 1904, mechanical filtration was introduced immediately following the famous typhoid fever epidemic studied and reported upon by Dr. George A. Soper. A comprehensive description of the city and its past and present water-supply is given in Dr. Soper's paper "The Management of the Typhoid Fever Epidemic at Watertown, N.Y., in 1904."[1]

We present herewith certain vital statistics for this city:

TABLE 20.
VITAL STATISTICS OF WATERTOWN, N.Y.*

YEAR	POPULATION	TYPHOID FEVER		TOTAL DEATHS	TOTAL DEATH-RATE PER 1,000
		Deaths	Death-Rates per 100,000		
Before filtration:					
1880	†10,697				
1888	13,919	7	50	294	21.1
1889	14,322	4	28	224	15.6
1890	14,725	6	41	234	15.9
1891	15,422	6	39	285	18.5
1892	16,119	8	50	371	23.0
1893	16,816	9	54	336	20.0
1894	17,513	15	86	312	17.8
1895	18,210	31	170	331	18.2
1896	18,907	9	48	312	16.5
1897	19,604	12	61	340	17.3
1898	20,301	19	94	291	14.3
1899	20,998	18	86	351	16.7
1900	†21,696	22	101	397	18.3
1901	22,446	8	36	347	15.4
1902	23,196	15	65	317	13.7
1903	23,946	17	71	356	14.9
1904	24,696	52	211	413	16.7
After:					
1905	‡25,447	6	24	384	15.1
1906	26,197	13	50	461	17.6
1907	26,947	10	37	504	18.7

* Compiled and computed from Reports of N.Y. State Dept. of Health.
† U.S. Census. ‡ State Census. Other population figures interpolated by the "arithmetical" method. Mechanical filter since September, 1904.

---

[1] *Jour. N.E. Water Works Assn.*, 22, p. 87.

For Watertown as for Binghamton we have plotted the general death-rate and that from typhoid fever (Chart 11). The irregularities in both curves are even more evident than in the case of Binghamton. Typhoid fever was apparently not reduced by the introduction of filtration to as low and as permanent a level as should have been expected, for in 1906 we find that the rate had again risen to 50. The total death-rate minus typhoid component, instead of showing a decrease in 1905, 1906, and 1907, actually shows a rapid rise. Here, then, we find apparently the direct reverse of the Mills-Reincke phenomenon, and this fact requires explanation. The authors have been unable to undertake any complete and personal investigation of the local conditions, but may venture to point out briefly several factors possibly of importance.

As in the case of Binghamton, we must regard as suspicious the great irregularities of the curves. Even at certain times of high epidemic prevalence of typhoid fever—notably in 1904, and also in 1895 and 1898—the total death-rate remained at a comparatively low level; while the highest total death-rate shown on the diagram occurred in a year (1892) when typhoid fever, tho excessive, and not reached nearly the proportions of later years. These fluctuations are undoubtedly due in part to the small numbers dealt with, for in a population of only 21,696 (for 1900) the small number of deaths each year leaves much room for serious percentage fluctuations. This circumstance, however, can hardly furnish more than the beginning of an explanation.

A much more important fact in connection with the non-appearance of the Mills-Reincke phenomenon is that the typhoid fever death-rate itself was not reduced after filtration to nearly as low a level as would have been expected. Even after nearly two years from the beginning of filtration, we find a rate of 50 (in 1906), while for 1907 and 1908 (figures for the latter year just published) the rates were 37 and 40 respectively. These rates throw a strong suspicion on the efficiency of purification, and if a considerable amount of infection still remains in the filtered water, the Mills-Reincke phenomenon ought not to have been expected to appear. This point we wish to emphasize particularly, for, if the excess of typhoid fever in Watertown in 1906–8 was due to the water, that fact would

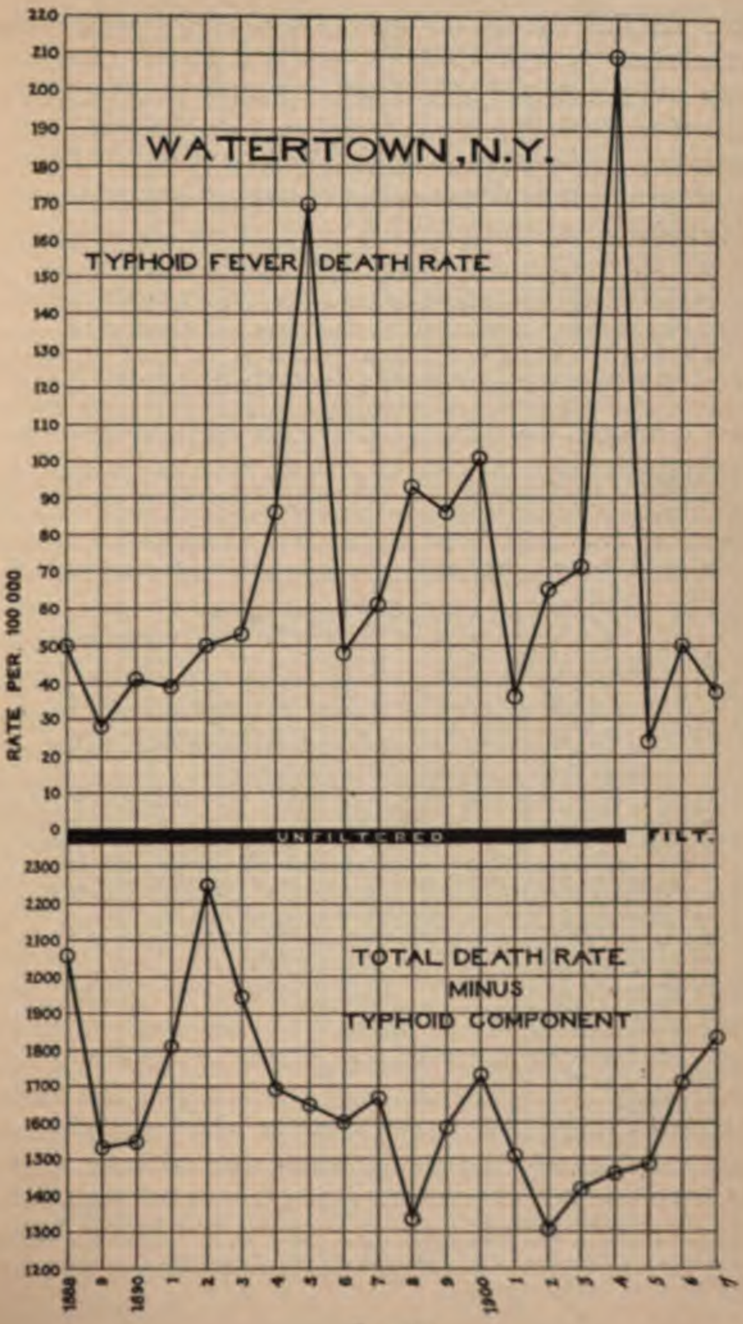

WATERTOWN, N.Y.
TYPHOID FEVER DEATH RATE
RATE PER 100 000
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
UNFILTERED
FILT.
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
TOTAL DEATH RATE
MINUS
TYPHOID COMPONENT
1888
9
1890
1
2
3
4
5
6
7
8
9
1900
1
2
3
4
5
6
7

CHART 11.

afford sufficient reason for the absence of the Mills-Reincke phenomenon.

We understand that acids or other chemical substances in the waters of the Black River have at times, especially of low water, been present in sufficient concentration to interfere with the proper operation of the city filters. Evidence of such chemical pollution is not far to seek.

> It is from the pulp and paper industries which have become well established on the river that the present gross pollution of the river is due. A number of mills are situated on the watershed with an aggregate output of over 300 tons of paper per day, in the manufacture of which sulphite pulp is used. Watertown is an active manufacturing city, and the river shows unmistakable signs of a high degree of pollution. All kinds of refuse are thrown directly into the stream, the paper mills and other factories using water in abundance to carry out factory wastes (Monthly Bulletin, N.Y. State Board of Health, July, 1908, p. 190).
>
> The effect of the chemical waste is quite apparent in times of low water in the river. A change of color of 25 parts per million (platinum scale) in four hours is not unknown here. . . . . This color change is frequently accompanied by a decrease in the alkalinity of the raw water (F. H. Jennings in discussion of above-mentioned paper by Dr. Soper, p. 137).

It may be objected that if there were sufficient concentrations of chemical wastes in the river to interfere with the operation of the filters, most or all of the bacteria in the water would be killed by their disinfecting properties, for there is no doubt that such wastes as those from pulp mills have a marked germicidal effect.[1]

But it is probable that the composition of the water fluctuates widely and rapidly, as is asserted in one of the above quotations, and it is quite conceivable that water of high disinfecting powers with low bacterial content today might incapacitate the filters for dealing with water of low disinfecting power and high bacterial content tomorrow.

XVIII. FLUCTUATIONS OF POPULATION IN PERIODS OF PANIC AND PROSPERITY AS SOURCES OF STATISTICAL ERROR.

Very early in our studies we were struck with the fact that the beginnings of filtration in Lawrence and of substitution of groundwater at Lowell coincided almost exactly with the panic of 1893, and the question naturally arose as to whether the diminished death-rates observed might not have been due, wholly or in part, to the influence of the panic. Our attention was first drawn to this important matter by newspaper references touching the effect of hard times upon health, particularly by an editorial in the Springfield (Mass.) "Republican" of June 30, 1908, from which it appeared that hard times are accompanied by a marked improvement in the public health. Corollaries were drawn to the effect that such improvement was doubtless due to less overworking, less overeating, less overdrinking, and the like—in short, to saner and more wholesome methods of living. And, certainly, following the period of financial depression in the United States setting in late in 1907, unusually low death-rates have been reported from many American cities. An article which has come to our notice, "Era of Low Mortality Reached by the Civilized World,"[1] states, for example, that for 1908 the death-rate for the registration states was, according to the U.S. Census, only 15.3 per 1,000 of population, this being, according to Dr. C. L. Wilbur of the Census, "probably the lowest death-rate that has ever occurred in the United States."

---

[1] See M. O. Leighton, "Prelim. Report on the Pollution of Lake Champlain," *Water Supply Paper No. 121, U.S. Geol. Survey, 1905*, Report of E. B. Phelps, p. 111. Also E. B. Phelps, "Pollution of Streams by Sulphite Pulp Waste," Paper No. 226 of *ibid.*, p. 7. Cf. *Penn. Health Bull.*, November 1909, on "The Germicidal Effect of Water from Coal Mines and Tannery Wheels upon Bacillus Typhosus, Bacillus coli, and Bacillus anthracis."

Our attention was independently drawn to the possibility of such an explanation as above mentioned of the lower death-rates at Lawrence by an employee connected with the registration of vital statistics in that city, who stated that to his personal knowledge there had taken place there, at the time of the panic of 1893, a marked change in the habits of the people, who began to spend more time in the open air, to make excursions into the country, and in general to live in a more leisurely and healthful manner. The new mode of life thus imposed upon the people was, it was argued, continued by force of habit even after the mills had again resumed full operation, more vacation time being then demanded by the employees. In the same discussion it was asserted also that there was a considerable change in the character of immigration at this time. It is, in fact, common knowledge among persons familiar with conditions in industrial cities that such phenomena do take place to a greater or less extent in hard times, with reverse effects in times of prosperity; and lower death-rates certainly have appeared in some cities at times of industrial depression.

---

[1] *Boston Med. and Surg. Jour.*, November 4, 1909.

On the other hand, there is good reason for believing that the plest and often the chief explanation of the diminutions in the *mputed death-rates* will be found in a temporary decline in industrial urban populations. In such case estimated populations for intercensal years would be inflated over their true values, and the rates based upon them would give false evidence of improvement in the public health. Thus there may be in many cases a considerable error which would be made manifest if annual, instead of quinquennial, or decennial, censuses were taken. This would of course be true of the U.S. Census method of estimation (used by us throughout), which gives for such cities, regardless of such possibilities, the same absolute increment from year to year between any two censuses.

To any objection based on a supposed effect of the panic of 1893 on the death-rates of Lawrence and Lowell—either through actual betterment of the public health or through diminished population—we answer first of all by calling to mind Manchester, N.H., a city in all important respects similar, which we have taken as a norm. Some influence upon the death-rates of Manchester, as of other cities, during the hard times might have been expected, but the fact is that no such influence is discernible in the figures. This indicates that the rates for Lawrence and Lowell remained uninfluenced from that source.

Altho satisfied that the results of our studies on Lawrence and Lowell are exonerated by the Manchester data from any serious blame on either of these points, we have thought desirable, nevertheless, to bring forward certain explanatory and confirmatory evidence, particularly in regard to possible diminutions of population in periods of panic. And in doing so we shall include also the case of Hamburg, where a panic was caused by the Asiatic cholera epidemic of 1892.

The cholera panic at Hamburg resulted in a temporary check to the growth of the population such as might be expected from an industrial panic. In fact, not only was the growth checked, but for a time the population was actually diminished, as observed by Dr. Reincke:

> While the population of Hamburg has in recent decades increased regularly by at least 2.6 per cent per annum . . . . it has in 1892 not only failed to increase but has actually decreased by 2,808 persons. . . . . Immigration into the city, which already

> at the beginning of the year was small, ceased entirely after the outbreak of the cholera, while emigration increased correspondingly ("Bericht des Medizinal-Inspektorats für das Jahr 1892," Hamburg, p. 1).

The observation thus recorded by Dr. Reincke would have been impossible without accurate statistics for the population from year to year, and we find that such statistics were in fact afforded by annual enumerations of population.

> In those years in which no censuses have taken place the Statistical Bureau of the Tax Commission has made since 1868 in the city and suburbs . . . . inquiries on population and dwelling conditions, including all data necessary for official purposes ("Statistisches Handbuch für den Hamburgischen Staat," 4te Ausgabe, Hamburg, 1891, p. 24).

This inquiry, made December 1, commonly called *Umschreibung*, approximates ever more and more the exactitude of the more detailed quinquennial census. Data are taken as to name, age, occupation, etc. The results are not, however, usually worked up in much detail.[1]

We call special attention to the fact that the death-rates given in Dr. Reincke's Annual Reports as well as in the "Sanitary History of Hamburg" (from both of which works we have in this paper freely quoted and drawn data) are based upon these annual enumerations of population.

Without further comment we present the results of the annual enumerations in the following diagram, based on figures taken from the "Sanitary History of Hamburg," p. 28. The dotted lines indicate for comparison the error which would have been introduced had there been only quinquennial or decennial censuses, with interpolation of the other years by the "arithmetical" or U.S. Census method. The maximum error due to this method would in this case have been with the quinquennial only 2 per cent, with the decennial 4 per cent.

It is evident that the recovery of population set in soon again after the panic of 1892–93, and was very rapid.

Turning next to Lawrence and Lowell and the question of the effect of the industrial panic of 1893 in diminishing the population growth of those cities, we have evidence that in them, as in Hamburg after the cholera scare of 1892, recovery in general public confidence

[1] Cf. Reincke, *Gesundheitsverhältnisse Hamburgs im 19. Jahrhundert*, p. 312.

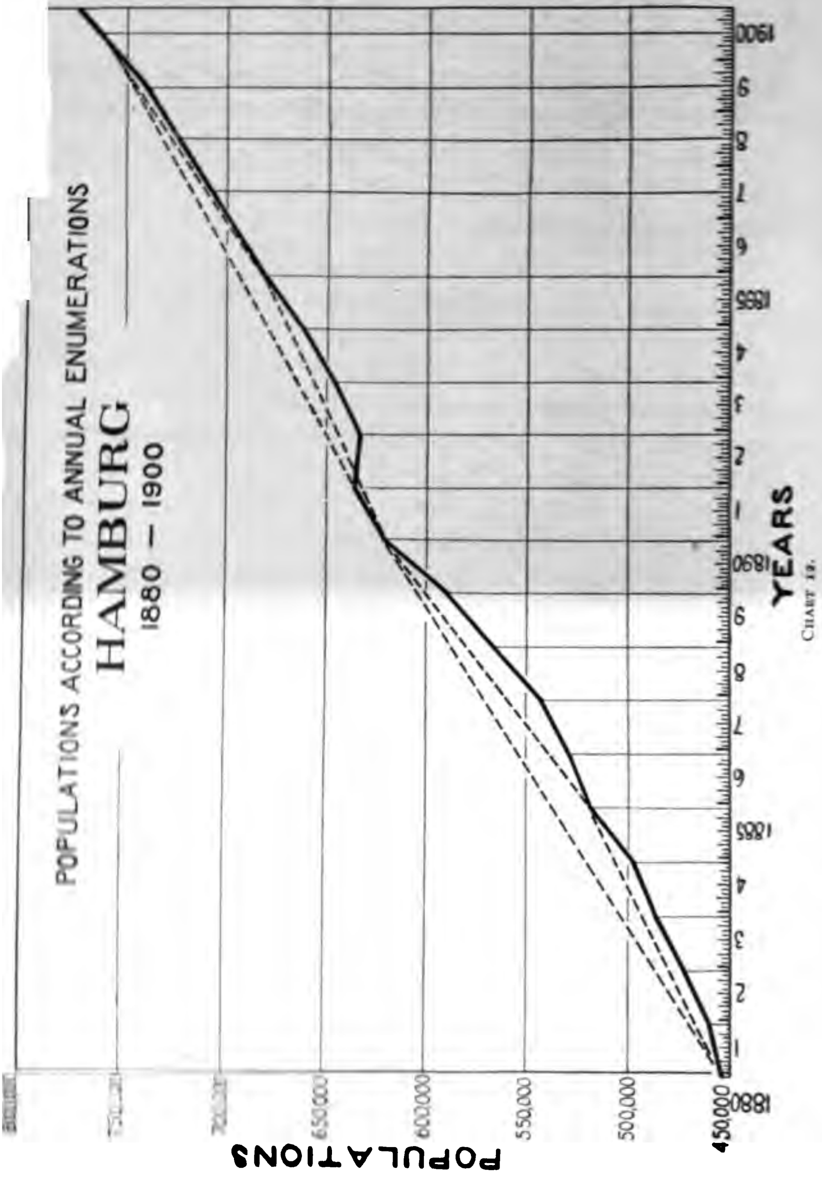

POPULATIONS ACCORDING TO ANNUAL ENUMERATIONS
HAMBURG
1880 — 1900
POPULATIONS
450,000
500,000
550,000
600,000
650,000
700,000
750,000
800,000
YEARS
1880
1
2
3
4
1885
6
7
8
9
1890
1
2
3
4
1895
6
7
8
9
1900

Chart 12.

and prosperity (with their corollary, increase of population) was early and rapid. There is first of all indication of this in the general financial and industrial movements in the United States at this time.

> Past experience has produced a number of instances where, in the second year after a great financial panic, business recovery went ahead so rapidly that it was found necessary, in the next year, to slow up. Of this the classic case in point was 1895. . . . . Sudden revival; active buying of merchandise; prediction of another "boom time"; spectacular rise in stocks, with Europe's capital enlisted; iron production surpassing all monthly records—these things were witnessed in the second year after 1893 ("The Nation," "Finance," February 24, 1910).

And this description is confirmed by the populations for Lawrence and Lowell given by the State Census of 1895. The characters of the populations had also, according to this census, remained practically the same.[1] Thus any fluctuations in quantity or character of population which may have taken place in 1893–94 were chiefly temporary. And certainly the much diminished death-rate computed for 1895 cannot be ascribed in any significant degree to error in the population statistics employed.

As an approximate indication of year to year fluctuations of population in Lawrence and Lowell, we have obtained, by courtesy of their city assessors, the total number of polls in those cities (enumerated for purposes of taxation), including practically all males over 20 years of age, as of May 1 of each year since 1889. These figures we have plotted in the following diagram, together with the total populations estimated by the so-called arithmetical method.

The panic and hard times of 1893–94 and the industrial depressions of 1903–4 and 1907–8 are seen to be clearly reflected in the curves for polls. The extent of fluctuation in these cities about 1894 was apparently somewhat greater than at Hamburg in 1892 and the following years. The indication from the Census of 1895 that the check to increase of population in 1893–94 was merely temporary, is confirmed. There was apparently also a check to growth of population in both cities following 1896, and this may perhaps be explained as a result of the secondary industrial depression which followed the revival of 1895.

The ratio of polls to total population remained fairly constant in both cities for the four census years, though more nearly so for wrence than for Lowell. Thus for Lawrence in 1890 there were persons in total population to each poll; in 1895, 3.69; in 1900, ; and in 1905, 3.84. For Lowell the corresponding figures are

---

[1] Cf. sec. xv.

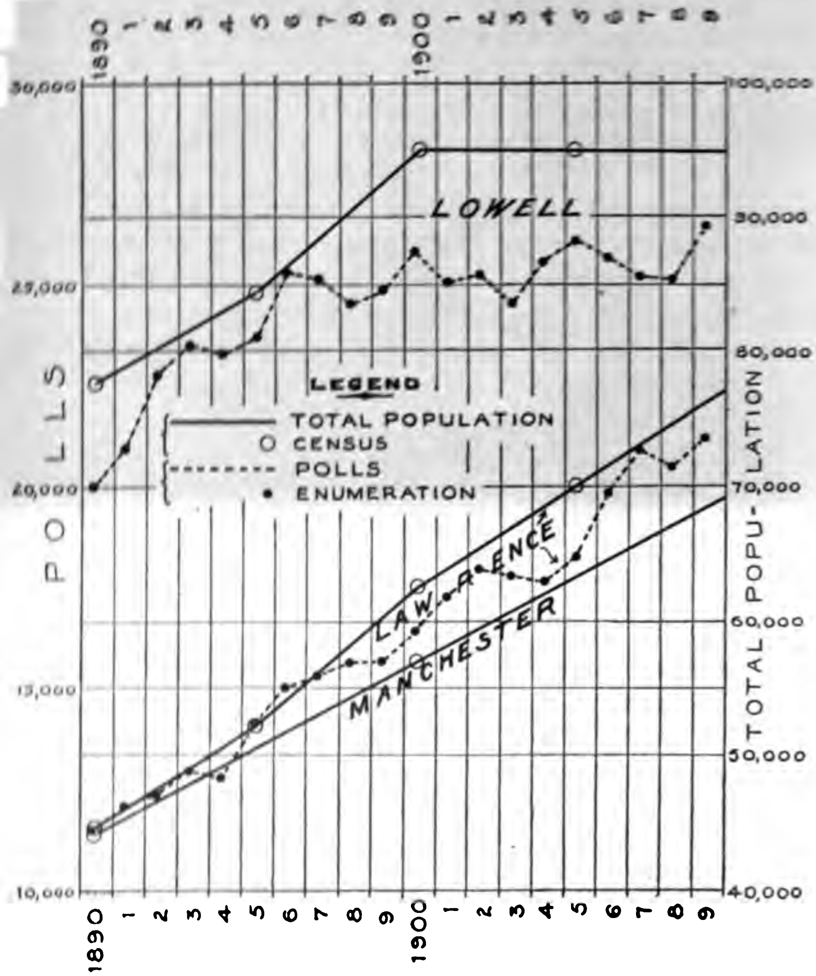


CHART 13.

3.88, 3.56, 3.68, and 3.64. These ratios afford a rough check on the accuracy of the poll enumerations, which tho of uncertain reliability, appear to be sufficiently accurate for the present purpose—i.e., an approximate indication of fluctuations of population.

In 1905 there was a diminution of the population of Lowell not paralleled at Lawrence, a difference which we have left without investigation as being unessential to our study.

We finally conclude, as to fluctuations in magnitude and character of population as sources of statistical uncertainty, that in particular years, especially where only a decennial census is to be had, errors seriously impairing the accuracy of death-rates computed from estimated populations may be introduced. The indications, however, from the curves just given, that the populations of Lawrence and Lowell had in 1895 recovered much of their former growth energy in spite of year to year fluctuations, taken with the evidence given in sec. xv on the elements of the populations and in secs. xv and xvi on Manchester as a norm, lead to the conclusion that no error seriously affecting our results can be attributed to fluctuations in magnitude and character of population.

XIX. SUMMARY AND CONCLUSIONS.

We may now bring together the various results of our study, as follows:

There is abundant evidence of the occurrence of the Mills-Reincke phenomenon, not only in the vital statistics of the cities of Lawrence and Hamburg, studied by Messrs. Mills and Reincke, respectively, but also for Lowell, Albany, and Binghamton. The phenomenon seems at first sight to be wanting in Watertown; but it is possible that in Watertown the purification of the public water-supply has been as yet relatively imperfect, and it is interesting to note that under these circumstances no diminution of the general death-rate has as yet occurred. For a fuller discussion of this point we must refer to the body of the paper.

We have not extended our studies over a larger range of cities, partly for the reason that trustworthy statistics for American cities are by no means common, and partly because of the incomplete and unsatisfactory character of investigations carried on at a distance. We earnestly hope that students of sanitary science who may fortunately have access to the necessary data for other cities will not fail to study and report upon the problems here raised. It is also greatly to be desired that similar studies should be made on the data afforded by such cities as Washington, D.C., in which the filtration of the public water-supply has not been followed by any material decline in the death-rate from typhoid fever; for in this case such filtration would not be expected to have produced any material decline in the total death-rate. Whether or not a partial purification of a public water-supply may be expected to be followed by a moderate decline in the total death-rate we cannot say, but the experience of Watertown would seem to indicate that this is not necessarily the case.

Mr. Hazen's quantitative expression for the Mills-Reincke phenomenon, when applied to the cities which we have studied (with the exception of Watertown), appears sound and conservative. It seems likely, however, that it will be impossible in the future to confine the relation even within the broad numerical limits suggested by Mr. Hazen. In fact, Mr. Hazen himself is very careful in this particular, as will be seen by a reference to his original statement (p. 510). It is probable that the pollution of a public water-supply may consist, at one time or in one place, of much typhoidal infection mingled with comparatively little sewage, or on the other had, of much sewage only lightly charged with typhoid fever germs. In the former case the reduction in typhoid fever might be out of all proportion to the reduction in general death-rate, and in the latter case vice versa. For Hamburg we have pointed out above that the saving in typhoid mortality was slight in comparison with the saving of mortality in other diseases combined, i.e., roughly only *ca.* 1 to 16. In the other cities studied we find ratios widely different from this, e.g., at Lawrence, 1 to 4.4, at Lowell 1 to 6.0, in Albany, *ca.* 1 to 4.1 (uncorrected), and in Binghamton only *ca.* 1 to 1.5 (uncorrected). It is clear, therefore, that Hazen's theorem is merely a convenient formula rather than a precise mathematical expression.

One of the most surprising results of our study will probably be the disclosure of the remarkable relation subsisting between polluted water and infant mortality. This subject has been more fully elucidated by Dr. Reincke than by anyone else, as will be evident from a perusal of his discussions quoted above. Our graphical demonstrations, however, are worthy of notice, as they bring out strikingly the principal facts. Students of preventive medicine will do well to extend these studies, which promise to shed much light upon the solution of one of the most serious problems of the time.

Closely associated with infant mortality stand diarrhea and gastro-intestinal disorders (90 per cent of which in Hamburg occurred among infants under one year of age) in relation to polluted water, which now bids fair to assume a causal importance in these diseases second only to that of contaminated milk.

In regard to tuberculosis the evidence, tho less striking, is interesting and suggestive. Inasmuch as we have been unable, even after the most careful investigation, to discover any other possible explanation of the figures, we are forced to the conclusion that a considerable portion of the decline in mortality from tuberculosis in Lawrence and Lowell during the years immediately following a change from polluted water-supplies was due to that change; and in line with this conclusion a similar explanation appears more than probable for Hamburg.[1]

For pneumonia, bronchitis, and the remaining infections, our data and diagrams speak with clearness, and we need not repeat the discussions we have already given in the preceding sections.

We have examined in detail the influence of fluctuations of population upon our statistical results, and find that no serious error has been encountered by us in that direction. It is certainly an interesting fact that the great panics have rarely if ever coincided with either federal or state censuses; but we find no reason to believe that the declines in either typhoid fever or the general death-rate in Hamburg, Lawrence, or Lowell, altho these happened to coincide with periods of panic, were in fact attributable to decrease of population.

Finally, the question naturally arises, to what is the decline of mortality observed in the Mills-Reincke phenomenon for diseases other than typhoid fever due? A little reflection will show that increase of vital resistance, due perhaps to the use of a purer drinking water, might produce this effect, while, on the other hand, the same results might be reached by an exclusion of disease germs formerly present and working upon the bodies of their victims. Or, as a l possibility, the phenomenon might be due to a combination co-operation of these two factors.

---

[1] See p. 185 of our paper in the volume *Tuberculosis in Massachusetts*, mentioned on p. 491 above.

is interesting to observe that Mr. Mills in his writings upon this ect, without especially committing himself to either hypothesis, apparently had in mind chiefly an increase of vital resistance, Dr. Reincke has expressed himself rather as looking to the moval of disease germs previously present.

The facts at present in our possession do not allow us to settle question beyond peradventure, and this problem, like many others raised throughout our paper, requires further elucidation.

THE FOUNDATIONS OF PREVENTION.

By WILLIAM T. SEDGWICK, Sc.D., of Boston, Professor of Biology, Massachusetts Institute of Technology.

One of the great characteristics of living things is their property of interfering with nature. Lifeless things may be said to submit tamely, helplessly, and mechanically to their surroundings, while living things even in the lower orders of life, react, resist, respond, and otherwise refuse to obey in a purely mechanical fashion the demands of their environment. The very idea of interference by lifeless things with the regular phenomena or laws of nature seems absurd. Rain, mist, fog, frost, not only obey natural laws but yield themselves without special resistance to gravity, electricity, heat and cold. The simplest living things, on the other hand, may struggle against gravity, move toward or away from heat or light, and, while in the larger way necessarily obedient to the laws of nature, are still in regard to these capable of special and irregular behavior. When, therefore, we find the objection raised, as it sometimes is raised, that preventive medicine is an interference with nature and natural law; that the prevention of infant mortality is likely to lead to race weakness; or when we encounter other superficial if not thoughtless criticisms concerning some of the most promising features of modern life, we shall do well to dig down to the foundations and to inquire What, after all, is the philosophy of prevention? Does the prevention of poverty lead to idleness, the prevention of premature death to overpopulation, the prevention of crime to the production of mollycoddles? We hear much of natural law and respect for natural law, and we do well to give heed to these things, but we must be careful not to confound obedience to natural law with a servile and unresisting submission to things as they are. Let us, on the other hand, inquire how things as they are came to be and whether a general conformity to natural law is not consistent with self-assertion and those more individual phenomena of life which gives it variety, spice and charm.

We may then begin at the beginning and examine somewhat carefully the foundations of interference with nature and natural law, one form of which is prevention of infant mortality, another the prevention of poverty, another the prevention of crime, another the prevention of disease. As we have said already, it is characteristic of lifeless bodies that these obey implicitly, mechanically and completely the established laws of nature, and follow in their fashion existing conditions. We have cited as an example the behavior of the various forms of water, and a similar mechanical obedience may be observed in the sands of the sea, in the gases of the atmosphere, in the clouds, and so far as we know in the heavenly bodies. These, to be sure, possess the universal property of inertia and accordingly exert a kind of passive resistance to change of every sort. But inertia is the most impersonal, the most inorganic, the most typically lifeless, because the most helpless, phenomenon in nature, and the resistance offered by inertia is simply involuntary obstruction to displacement, and opposition to change of every sort.

With this implicit, mechanical obedience to nature goes, it is true, a calmness, a quietism, which has excited the envy of the poets:

> "And a look of passionate desire
>   O'er the sea and to the stars I send;
> Ye who from my childhood up have calmed me,
>   Calm me, ah, compose me to the end."

When, however, we turn away from the inorganic world to the lowest forms of life—protozoa or protophytes—we enter another region. Living organisms, while necessarily obedient to the larger laws of nature and strictly conditioned by temperature, gravity, light and other fundamental phenomena, show, nevertheless, important reactions, responses, movements and other properties through which they actively resist, and may even refuse to obey, the less imperative calls of their environment. And as we rise in the scale toward higher plants and higher animals, we find a constantly greater and greater tendency not to yield passively to environment, typified at its best and largest in men like Tennyson's Ulysses:

> "Made weak by time and fate, but strong in will,
> To strive, to seek, to find and not to yield."

This tendency often amounts to an actual control of many elements of environment by living things in their own interest, and it is worth while to observe, in passing, that competition and the struggle for existence arise in large measure because of this tendency toward controlling environment, for if all organisms should weakly yield to the things about them, there would be no "struggle" for existence and, because all would be doing the same things, no active competition.

Herein also lies the weakness of the doctrine of *laisser faire*, which virtually assumes that interference with human nature should be avoided or at least minimized. But to let nature wholly have her way is to revert to savagery; and while self-development is perhaps the highest form of development which we know, it is by no means so common or so certain as to make unnecessary frequent altruistic interference, or even social regulation.

With the theory of prevention in general thus in mind, we
may pass on to its illustration by examples. And first let us
glance for a moment at a form of prevention which finds every-
where universal acceptance, *viz.*, the prevention of crime. The
prevention of murder, or the theft of life, of robbery, or the
theft of property, and of assaults of every sort harmful to the
the other hand, the prevention of waste has never yet come to
police power is invoked and they yield to social control. On
individual fails to abate those for which he is responsible, the
isms. So, also, it is with the prevention of nuisances. If the
their application, they have become not merely truths but tru-
control—or both. And since no one questions these ideas or
or the substitution for this of the police power—that is, social
person require either the promotion of individual self-control
be recognized as amenable to social control, and unless the in-
dividual seeks to compass it—as in America he generally does
not—nothing is done. Midway between the prevention of
crime and the prevention of waste stand such forms of preven-
tion as that of disease, in which the individual is expected to
do most, but the police power some, of the work—the proportion
expected from each varying with the disease to be prevented.

[illegible] all-powerful
[illegible] the like. If
[illegible] individual
[illegible] mortality,
[illegible] have been,
[illegible] difference, how-
[illegible] too evidence
[illegible] but yet
[illegible] unhappily wasted.
[illegible] use in
[illegible] way
[illegible] young
[illegible] have failed to
[illegible]
[illegible] and
[illegible]
[illegible]
[illegible] natural
[illegible]

Pearson that the prevention of child labor is likely to lead to race suicide. It has been objected by others that the prevention of infant mortality will have the opposite effect and—assumption upon assumption—it is assumed in both cases that these consequences are obviously pernicious. We may, however, reasonably doubt both of these theorems and their corollaries, for it clearly is not safe to dogmatize in this matter, because no one has yet proved that race control—the so-called "race suicide"—is necessarily disadvantageous, or that the prevention of infant mortality is unwise. Instinctively, we feel that such control and prevention are prevention desirable, and if we ask for justification for them, it is not hard to find, along the lines already indicated.

What then shall be our mechanism of the prevention of infant mortality? Is it not, first, protection against, by interference with, natural conditions—just as birds build their nests for shelter against weather and against their enemies; and, next, feeding, such as shall comfort, support, develop, and cheer; and then police guardianship against vagrant infectious disease; and finally, and best of all, intelligent parentage? Let us examine somewhat carefully each of these foundation stones in the general structure of scientific prevention.

We have all heard of the "exposure" of infants, a term which describes a hideous practice in certain Asiatic countries, under which infants deemed superfluous are left to the non-human care of nature and speedily perish, exposed to weather, wild beasts, or whatever conditions may happen to surround them. In most cases, however, even among savages, some shelter is immediately cast about the new-born child, even if this be no more than that of the wigwam, the tent, a piece of clothing, or other rudimentary appliance. And going to the other extreme, we know how complete in the best ordered homes of to-day is the protection immediately thrown about the new-born child, only to be continued and, if possible, perfected during the first few months of infant life. Care of this sort has long been given among the well-to-do even in the prenatal period, and a movement now on foot in Boston provides it for some who would not otherwise have had it.

The Women's Municipal League of Boston, according to one of its officers, Mrs. William Lowell Putnam, chairman of the Committee on Infant Social Service, has begun with . . . the mother . . .

Feeling that bad prenatal influences could not be too early cared for, the League is working with pregnant women quite as much as with babies . . . Two nurses are employed, one giving her time to the pregnant women, the other to the babies and their mothers.

The League is trying to see how many more babies may be healthily brought into the world and carried healthily through their first year by proper teaching of the mother, and also incidentally how many mothers' lives can be saved by preventive work with them.

When we come to the support and maintenance of the new-born child we see all sorts of care extended by the mother, from that best, though most primitive, form of maintenance, in which the mother surrenders to the child portions of her own body in the form of milk, up to the most elaborate incubator arrangements of modern times. In average communities we get in [illegible] [illegible] the more highly civilized community interference with nature by the [illegible] of the state to [illegible] protection against infectious diseases, so that the new-born child shall be protected as far as possible from those various kinds of different death which may roam through the community. Here we have the basis and in some cases the high development of Board of Health work, together with such forms of municipal sanitation as the control of street dust, the supply of pure water and pure fresh milk and the suppression of smoke.

And finally, or perhaps first of all, we have in men, and especially in highly civilized men, that intelligent interference with nature which can only be accomplished through intelligent parentage and the scientific supervision of infant life by wise and educated parents. Social control contained in official protection by authorized agents of the community and family supervision brought about by intelligent parentage, are the two phenomena which ought to distinguish the best conditions from the worst. In the worst everything is left to unaided nature, in the best, nature is duly regarded but yet wisely interfered with, aided, and controlled.

And how shall we secure these two great foundation stones for our modern social structure? I know of no other way than by making biology, the science of life and of living, the beginning and the end of our educational endeavor. We have studied the skies and the stars; we have philosophized on man and his destiny; we have built machines to do our work and sky scrapers to work in; we have learned how to imprison men and how to kill them, in war and in peace; but we have not yet studied biology, or learned many of the most fundamental lessons of the science of life.

Discussion of infant mortality in the 18th century centered largely around infant damnation. In the 19th century it shifted to post-mortem salvation, but in the twentieth it is turning toward prevention. So long as one of the most powerful intellects of the 18th century—Jonathan Edwards—could affirm that infants, not of the elect, "are, in the sight of God, as young vipers," it was natural for mere common folk to contemplate an excessive infant mortality, not perhaps with satisfaction but at least with resignation.

The watchword of a scientific age is prevention. The prevention of waste, the prevention of poverty, the prevention of crime, the prevention of pain, the prevention of disease and the prevention of premature death, to-day are debated as never before. But scientific prevention, precisely because it involves more or less interference with nature, requires for its foundations the completest possible knowledge of nature—including human nature—and of natural law; and above all more careful studies in biology, the science which lies at the basis of all knowledge of life and health and death. We must have also more and better training in all sorts of applied biology, such as hygiene and sanitation and eugenics, and medical sociology before we can expect to interfere wisely with natural processes or to control successfully the blind forces—of nature at work about and upon and within us.

The

Journal of Infectious Diseases

FOUNDED BY THE MEMORIAL INSTITUTE FOR INFECTIOUS DISEASES

Vol. 7 *January 15, 1910* No. 1

A COMPARATIVE STUDY OF INTESTINAL STREPTOCOCCI FROM THE HORSE, THE COW, AND MAN.*

C.-E. A. Winslow and G. T. Palmer.

(From the Biological Laboratories of the Massachusetts Institute of Technology.)

INTRODUCTION.

The first real clue to the systematic relationships of the streptococci was furnished by Gordon when he pointed out that these organisms could be separated into well defined groups by a study of their fermentative reactions in various carbohydrate media (Gordon, 1904; Gordon, 1905). Houston carried forward the application of Gordon's tests (Houston, 1905; Houston, 1906); and finally Andrewes and Horder (1906) founded upon all these results a rational classification of the genus into seven main types or species. The basis of their division was statistical or biometrical. It involved the examination of records of many individual cultures (1,200 in the case of the streptococci) and the study of the frequency with which various characters, or combinations of characters, occurred. Type centers, according to the statistical method, are defined by the occurrence of a large number of individuals with a given characteristic. These common types, among such variable organisms as the bacteria, may properly be considered as representing species, about which the rarer varieties are grouped.

---

* Received for publication October 22, 1909.

The chief characters of the species of streptococci thus defined by Andrewes and Horder are indicated concisely in the table below (Table 1). Strept. equinus is described as characteristic of the intestine of the herbivora. It was abundant in horse-dung and was the commonest form in the street air of London. All the other forms were primarily of human origin, Strept. mitis and Strept. salivarius from the normal throat, Strept. fecalis from the normal intestine, and Strept. pyogenes and Strept. anginosus from diseased conditions.

TABLE 1.

TABULAR CLASSIFICATION OF THE STREPTOCOCCI
(Andrewes and Horder, 1906.)

SPECIES	CHARACTERISTICS								
	Milk Clot	Neutral Red	Saccharose	Lactose	Raffinose	Inulin	Salicin	Coniferin	Mannit
Strept. equinus	−	−	+	−	−	−	+	+	−
" mitis	−	−	+	+	−	−	+	−	−
" pyogenes	−	−	+	+	−	−	+	−	−
" salivarius	+	+	+	+	+	−	−	−	−
" anginosus	+	+	+	+	+	−	−	−	−
" fecalis	+	+	+	+	−	−	+	+	+
Pneumococcus	+	−	+	+	+	+	−	−	−

One of the most interesting practical points about this classification lies in the fact that all the six streptococci of human origin ferment lactose, while Strept. equinus, which Andrewes and Horder hold to be characteristic of the intestine of the herbivora, fails to do so. If a general distinction between human and animal streptococci could be demonstrated it would prove of much practical, as well as theoretical importance. Sanitarians are continually seeking, and seeking in vain, for some criterion by which sewage pollution of human origin may be distinguished from the surface wash of streets and agricultural land. The colon bacilli from the intestines of various warm blooded animals have been shown in many investigations—the latest and most exhaustive coming from Dr. Bettencourt's laboratory at Lisbon (Ferreira, Horta, and Paredes, 1908; Bettencourt and Borges, 1908*a* and 1908*b*)—to be identical. If the streptococci should prove to be characteristic it would greatly aid the water analyst.

The work of Gordon, and Andrewes and Horder, to which reference has been made, pointed to lactose as the best differential medium for distinguishing human and animal streptococci. These investigators showed clearly that a large proportion of streptococci of human origin ferment lactose while most of those derived from horse-dung or street air fail to do so. On the other hand Houston (1906) in the examination of cow-dung obtained widely different results. Eighty-five per cent of his cultures from this source fermented lactose; but their reactions in mannit, raffinose, and neutral red were somewhat characteristic. Mannit was fermented by 24 per cent of the human cultures and by none of the bovine strains; raffinose was fermented by 32 per cent of the human and by 74 per cent of the bovine cultures; neutral red was reduced by 39 per cent of the human strains and by none of those from cow-dung.

These results suggest that both the horse and cow have characteristic types of intestinal streptococci which differ from each other and from those commonly found in the intestine of man. Our object in the present investigation was to confirm this conclusion by the study of a new series of cultures from the three sources. In particular we wished to obtain quantitative results with regard to the amount of acid formed in various media. This aspect of the question has been ignored by all the English observers, who are content merely to classify their cultures as fermenting or non-fermenting. Recent studies of the Coccaceae as a whole have shown however that exact quantitative data are of much value in classification (Winslow, 1908). We chose dextrose, lactose, raffinose, and mannit as the carbohydrates to be tested. Dextrose serves as a type of the simple sugars which are fermented to some extent by almost all streptococci. Lactose and raffinose represent, respectively, the aldehydic and anhydric groups of sugars. Mannit represents the alcohols. Three hundred and two strains of streptococci, from human, equine, and bovine feces, were grown in broths containing these carbohydrates and the resulting acidity in each case was determined by titration. The results as analyzed below indicate definite and characteristic differences between the streptococci from the three species of animals.

Methods.—All the streptococci studied were isolated from fresh feces, collected in a sterile tin can with tight-fitting cover. Human feces were deposited directly in the can while horse-dung and cow-dung were taken from the stable floor within a few minutes after ejection. Streptococci were isolated from 15 samples of human feces, 12 samples of horse-dung, and 22 samples of cow-dung. In all cases care was aken to remove the outer layer of the feces and to take samples from the interior in der to avoid contaminations from stable floor or air.

The attempt was made at first to isolate the streptococci by inoculating a loop of es into dextrose broth, incubating for various periods from 4 to 96 hours, and then ating on agar. This procedure is effectual in isolating streptococci from polluted ater; but with feces it utterly failed in our hands. Spore-forming bacilli were found upon the plates or no growth appeared at all. It is probable that the streptococci were overgrown by other bacteria, perhaps by forms like B. acidophilus.

We therefore adopted the method of direct plating on agar without any preliminary enrichment whatever; and this proved generally successful. Two or three heavy platinum loopfuls of feces were well shaken up in 10 c.c. of sterile water and two or three loops of the resulting suspension carried over to a tube of melted agar. This was poured into a Petri dish and incubated at 37° for 24–48 hours. Agar streak cultures were made from minute round colonies on these plates and the appearance of these streaks after 24–48 hours at 37° was generally characteristic. Streaks showing a faint veil-like growth or a few dotted colonies or a thin line confined to the streak itself were almost always streptococci. In isolating the first 210 strains a microscopic examination was made. Smears were stained for 30 seconds with cold carbol fuchsin and cultures showing chains, pairs, or single cocci were accepted. In every one of these 210 cases the microscopic examination confirmed the conclusion based on the macroscopic appearance; and we are confident that the characteristic growth of the streptococci can be easily recognized by the experienced observer. Heavy growths on the streak always proved to be bacilli. Chromogenic, vigorously growing staphylococci were not found at all.

Streptococci were least easily detected on the plates made from cow-dung. The latter showed a great many small white colonies from which selection was difficult. Four out of five cultures streaked from cow-dung proved to be bacilli while not one out of five of the cultures isolated from horse-dung as streptococci failed to prove so.

A rough estimate was made of the total number of bacteria in one sample of each of the three kinds of feces, by plating high dilutions on agar, and incubating at 37° for 48 hours. The number of streptococci was estimated by isolating and identifying colonies which seemed characteristic. The sample of human feces showed an average of 8 million bacteria per gram of wet feces and 2,500,000 were streptococci. The proportion of streptococci is somewhat higher than that reported by MacNeal, Latzer, and Kerr (1909) who found that streptococci made up from 10 to 20 per cent of the total bacteria present. This is perhaps because MacNeal and his associates determined their total count by direct enumeration under the microscope, while our "total" is only the agar count at 37°. It is probable that most of the intestinal cocci grow on ordinary laboratory media, while we know that many bacilli and spirilla do not. In the sample of the horse feces we found an average of 3 million bacteria, of which nearly half were streptococci. This corresponds with our general experience of the high proportion of streptococci in equine feces. Cow-dung on the other hand showed in the sample examined an average of 100 million bacteria per gram of wet feces, of which 10 million were streptococci. This small ratio of streptococci (altho the actual numbers were high) explains the difficulty experienced throughout in isolating streptococci from cow-dung.

An interesting individual case was met with in the study of human feces, in which streptococci could rarely be found at all and in which all bacteria growing on ordinary media were present in comparatively small numbers. Altogether the feces of 11 different persons were examined and streptococci were easily isolated in 10 cases. From this one individual, 7 samples were taken and 67 plates were made by the usual method (a loopful or two from feces to 10 c.c. water and a loopful or two of water to a plate). Only 22 out of the 67 plates showed growth and but 6 showed streptococci.

By the methods described above 302 cultures of streptococci were obtained in all, 116 from man, 100 from the horse, and 86 from the cow. As soon as a streak proved positive it was inoculated into broth tubes containing the four carbohydrate media tested. These were incubated for 72 hours at 37° and then titrated. Five c.c. of the liquid in each tube was measured out into a graduate, mixed with 45 c.c. of distilled water, and titrated in the cold against $n/20$ NaOH, using phenolphthalein as an indicator. Blank titrations were made at the same time on sterile tubes of the same batch and their results subtracted from those obtained for the inoculated tubes. The media used were in all cases made up with one per cent Witte's peptone, 0.25 per cent Liebig's beef extract, and one per cent of the carbohydrate to be tested.

Positive acid reactions were generally associated with obvious appearances of growth in the form of profuse white sediment along the bottom and sides of the tubes. In a very few cases, however, acid was produced in tubes which appeared clear to the eye.

In the case of negative tubes, with no rise in acidity and no turbidity or sediment the lack of development might conceivably be due to a failure of inoculation. Great care was taken however to transfer as much of the cultures as could be carried on a platinum loop. The fact that obvious growth almost always occurred in the dextrose broth tubes shows pretty clearly that inoculation was not at fault. The contents of 49 of the clear tubes of various media were examined by plating out on agar. Three tubes showed many colonies, 15 showed 1 to 6 colonies, and 31 showed none. It may reasonably be assumed that in such cases the streptococci introduced had simply failed to develop and gradually died out on account of the lack of suitable carbohydrate pabulum, upon which these organisms appear to be highly dependent.

RESULTS.

The results of the individual titrations are given in tabular form at the end of the paper. The first column indicates the culture examined, and the second, the number of the sample of feces from which it was derived. The figures for acidity represent the difference between the value obtained for each culture and the value of an inoculated control incubated under similar conditions. The results are probably significant within 0.2 per cent acidity.

A clearer idea of the meaning of these results may be gained from an inspection of Table 2 in which they are grouped together into acidity-classes, and from Charts 1, 2, 3, and 4, which have been plotted from the values in Table 2.

Dextrose is fermented more or less vigorously by practically all the streptococci from human and equine feces, but the streptococci

of man produce a markedly greater amount of acid than those from horse-dung. The mode for the human cultures lies between 3.6 and 4.0 per cent; that for the equine cultures between 1.6 and 2.0 er cent. The streptococci from cow-dung exhibit two distinct and ly marked types, one forming about 2.0–2.5 per cent acidity, aching the value of those from horse-dung, and the other group, out the same numerical importance, forming no acid at all.

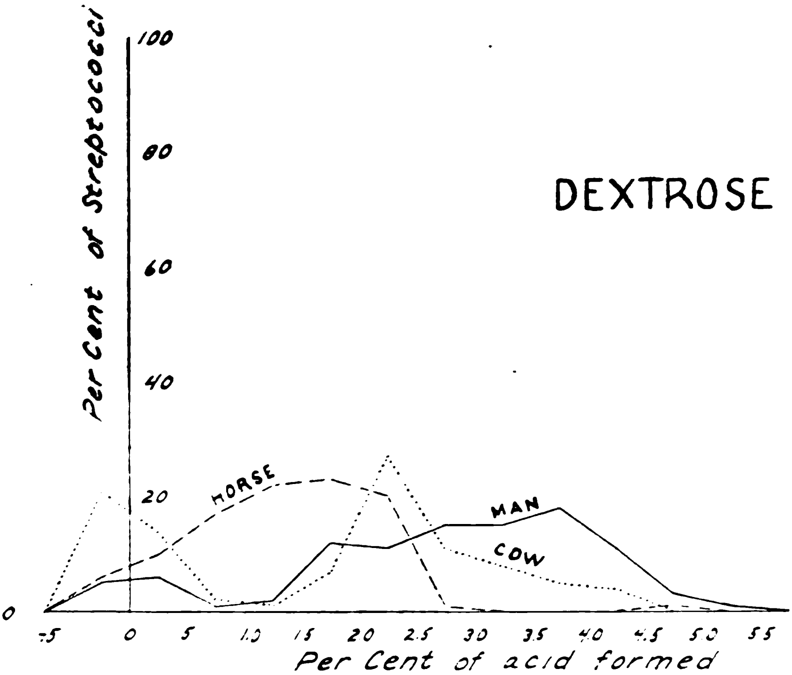


Chart 1.—Acid producing power of streptococci in dextrose broth.

In lactose the human and bovine cultures show two distinct types, one group yielding an acidity between 2.6 and 3.0 per cent, the other group producing no acid reaction at all. In the horse feces only the non-acid type is found.

Raffinose is not acted upon by any appreciable number of human or equine cultures. On the other hand, in the feces of the cow a small but clearly marked group appears, forming an acidity between 2.1 and 2.5 per cent.

Mannit is apparently not fermented by any important number of streptococci in the horse or cow but is acted upon by a small but definite group of the human strains.

TABLE 2.

STREPTOCOCCI GROUPED IN PER CENT ACIDITY CLASSES.

	−.5 0	.1 .5	.6 1.0	1.1 1.5	1.6 2.0	2.1 2.5	2.6 3.0	3.1 3.5	3.6 4.0	4.1 4.5	4.6 5.0	5.1 5.5
					Man (116)							
Dextrose	6	7	1	2	14	13	17	17	21	13	4	1
Lactose	20	24	2	5	17	11	24	12	1	0	0	0
Raffinose	34	75	2	1	0	1	2	1	0	0	0	0
Mannit	47	36	6	4	12	0	1	0	0	0	0	0
					Horse (100)							
Dextrose	6	10	17	22	23	20	1	0	0	0	1	0
Lactose	66	26	4	2	1	0	1	0	0	0	0	0
Raffinose	54	42	1	0	2	1	0	0	0	0	0	0
Mannit	62	36	0	1	1	0	0	0	0	0	0	0
					Cow (86)							
Dextrose	18	12	2	1	6	23	0	7	4	4	0	0
Lactose	27	14	1	0	8	8	20	8	0	0	0	0
Raffinose	36	26	0	3	6	11	3	1	0	0	0	0
Mannit	54	27	2	3	0	0	0	0	0	0	0	0

These results are compared in a general way with those obtained by Houston (1905, 1906) and Andrewes and Horder (1906) in Table 3. In classifying our own results for this table we have considered all results under 0.5 per cent as negative. The various investigations are concordant with the exception that raffinose-fermenters in both human and bovine feces were less frequent in our observations than in those of Houston. Our results also indicate a somewhat lower percentage of lactose-fermenters. All the investigations show that streptococci from the human intestine generally attack lactose while some strains ferment mannit; bovine strains attack lactose or raffinose; and equine strains dextrose only.

TABLE 3.

COMPARATIVE RESULTS OBTAINED BY VARIOUS OBSERVERS IN REGARD TO FERMENTATIVE POWER OF INTESTINAL STREPTOCOCCI FROM VARIOUS SOURCES.

SOURCE OF FECES	OBSERVER	NUMBER OF CULTURES	PERCENTAGE OF POSITIVE RESULTS			
			Dextrose	Lactose	Raffinose	Mannit
Human	Houston	300	..	76	32	24
Human	Winslow and Palmer	116	89	62	6	28
Equine	Andrewes and Horder	13	..	0	0	0
Equine	Winslow and Palmer	100	84	8	4	2
Bovine	Houston	100	..	85	74	0
Bovine	Winslow and Palmer	86	65	52	28	6

In determining what types of streptococci are present in each species of animal, the correlation of fermentative power must be taken into account, as well as the activity of the organisms in each particular sugar. In the horse the problem is a simple one for all the organisms studied belong to a single type, characterized by a moderate acid production in dextrose broth and failure to attack either of the other carbohydrates. This is clearly the Strept. equinus described by Andrewes and Horder. In the human and bovine feces, on the other hand, the problem is more complex, and can best be understood by grouping the organisms according to their relation to all the carbohydrates studied, which has been done in Table 4.

TABLE 4.

INTESTINAL STREPTOCOCCI OF HUMAN, EQUINE, AND BOVINE ORIGIN, GROUPED ACCORDING TO THEIR FERMENTATIVE REACTIONS.

CARBOHYDRATE FERMENTED	NAME OF TYPE	PERCENTAGE OF STREPTOCOCCI FOUND IN		
		Man	Horse	Cow
None		9	15	18
Dextrose alone	**S. equinus**	23	73	27
Lactose alone		2	0	5
Dextrose and lactose	**S. mitis**	31	5	21
Dextrose and raffinose		0	3	3
Lactose and raffinose		0	0	12
Dextrose, lactose, and raffinose	S. salivarius	5	0	0
Dextrose, lactose, and mannit	S. fecalis	23	0	2
All four		0	1	3

One of the most striking results of this tabulation is the confirmation it affords of the reality of the type centers established by Andrewes and Horder. The strains which fermented no carbohydrates at all may be considered as weak forms which failed to establish themselves in any of the media. Aside from this class the only large groups of organisms were those named as type centers by the English observers, Strept. equinus, Strept. mitis, and Strept. fecalis. Strept. salivarius comes next; and the other combinations of characters are exhibited by so few strains that, with one exception, they may be considered as isolated variants from the commoner types. The single exception which may prove significant is the type fermenting lactose and raffinose but neither dextrose nor mannit, which made up 12 per cent of the fecal streptococci of the cow. If further study should confirm these results this type may deserve a specific name of its own.

Reviewing the results as arranged in Table 4 it appears that equine feces contain only one common type of streptococci, Strept. equinus, which attacks dextrose but cannot ferment the other carbohydrates.

In the streptococci of human origin on the other hand there are three common types. Of our 116 human cultures, 27 fermented dextrose only, 36 dextrose and lactose, and 27 dextrose, lactose, and mannit. The first type is clearly allied to Strept. equinus; but, while these streptococci exhibit the same general qualitative relations to the sugars in the horse and man, their vigor of fermentative power, when measured quantitatively, is somewhat different. The equine strains as pointed out above produce an acidity in dextrose of about 2.0 per cent and the same is true of the bovine forms. On the other hand the human streptococci produce almost twice as much acid. There is apparently a distinct variety of Strept. equinus characteristic of the human intestine which may be recognized by its high fermentative power as measured in dextrose broth.

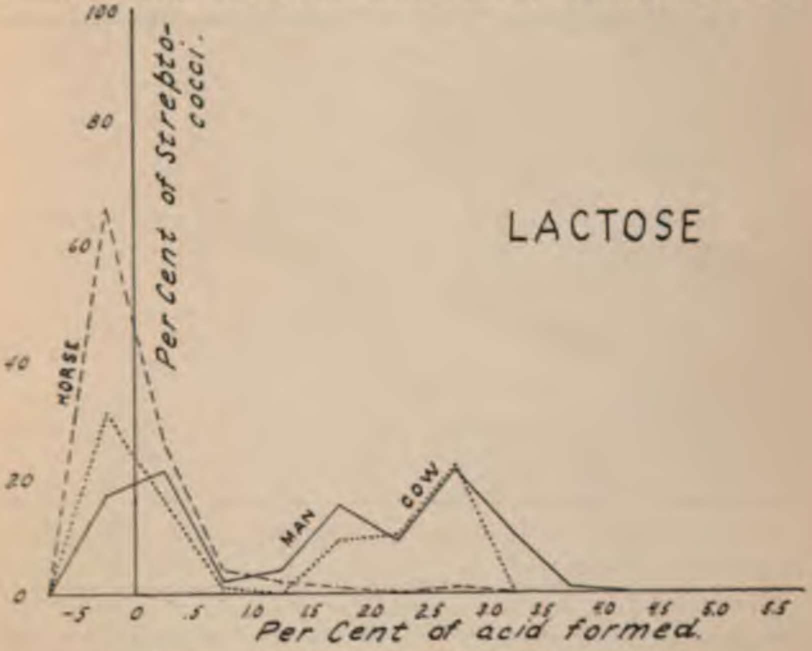


CHART 2.—Acid producing power of streptococci in lactose broth.

One interesting point about the non-lactose-fermenting streptococci of human feces, whether of the Strept. equinus type or of the group of weakened organisms which fermented neither sugar, was their association with diarrhea. We were especially anxious to see if acteristic streptococci were associated with this condition; and the 15 samples of human stools examined were more or less diar- al in nature. Of 31 streptococci from normal stools, only 4 failed to ferment lactose; while of 85 strains from diarrheal stools 36 formed no acid from that sugar. Twenty-seven of the 36 fermented dextrose vigorously and 9 were weak forms which produced no acid in any medium. The 27 strains which fermented dextrose only form an interesting group differing, as noted above, in the amount of acid produced, from the type Strept. equinus. Twenty-four of these 27 organisms came from a single individual, appearing in three different samples of diarrheal stools. Altogether 47 strains of streptococci were isolated from these three stools; 24 of them were of the Strept. equinus type and 19 of the 24 formed more than 3 per cent acid in dextrose. The other three human strains of Strept.

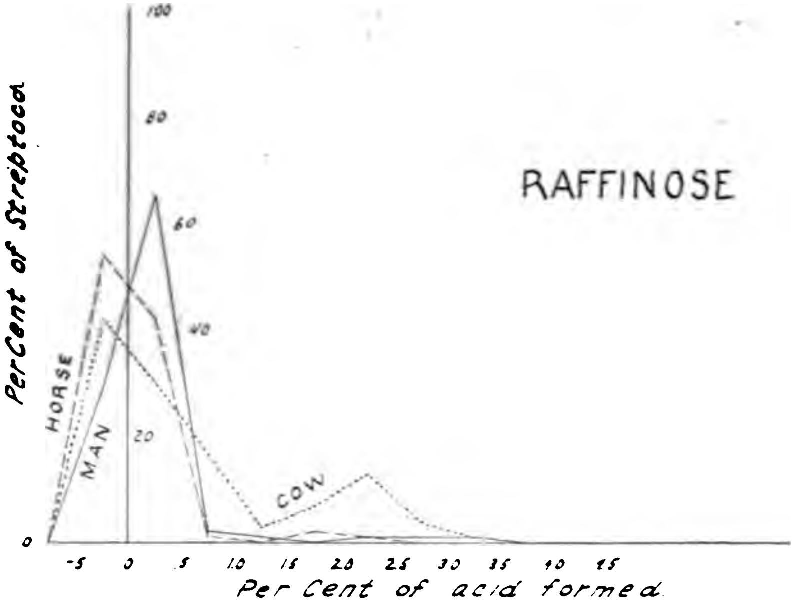


CHART 3.—Acid producing power of streptococci in raffinose broth.

equinus were from the diarrheal stools of other persons; and the connection may prove to be something more than a personal idiosyncrasy.

The second type of streptococci found in human feces, the first in point of abundance, was Strept. mitis, which ferments dextrose and lactose but not raffinose and mannit. This organism was the commonest form in human feces and second in abundance in cow-dung.

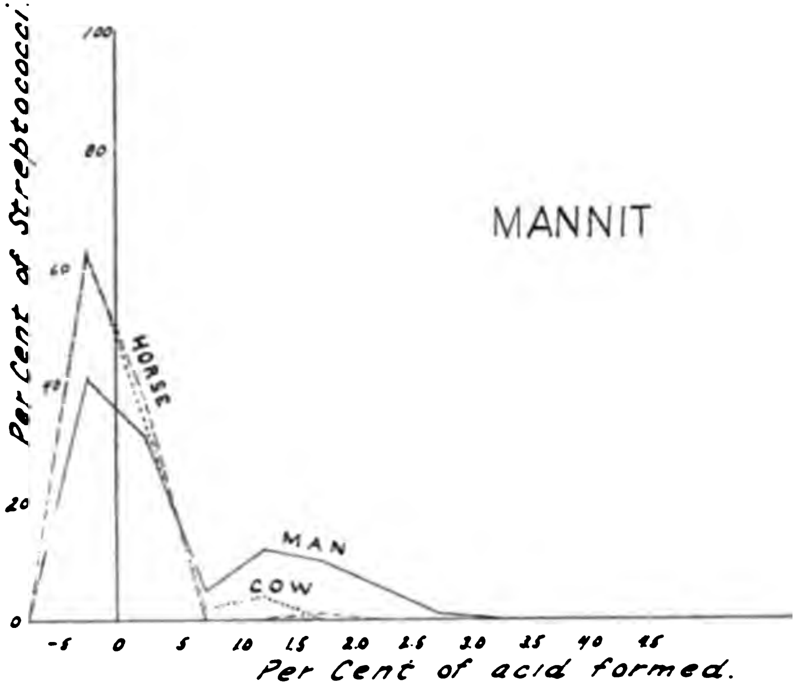


CHART 4.—Acid producing power of streptococci in mannit broth.

Finally 23 per cent of the human strains belonged to the type of Strept. fecalis, characterized by fermentation of dextrose, lactose, and mannit. This form was not found at all in the feces of the horse and but twice in that of the cow, these results corresponding closely with those obtained by Houston.

The intestinal flora of the cow appears to be more complex than either of the others. Strept. equinus and Strept. mitis are the commonest types but two other forms were also present in considerable numbers. Nine per cent of the strains belonged to the type of Strept. salivarius, characterized by the fermentation of dextrose, lactose, and raffinose. Twelve per cent of the cultures were of a new type, not apparently described hitherto, having the peculiar property of attack-

TABLE 5.
STREPTOCOCCI ISOLATED FROM HUMAN FECES.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	45	4.4	3.0	.1	.1	59	78	3.3	0	−.2	−.1
2	46	3.3	2.7	.4	1.7	60	78	2.9	0	+.2	−.1
3	46	3.9	3.0	.2	1.6	61	78	1.1	.2	+.2	−.2
4	46	3.6	2.8	0	.2	62	78	3.5	0	.1	0
5	47	3.4	3.9	.2	1.5	63	78	2.9	0	−.1	−.3
6	47	3.9	2.8	.2	.1	64	78	1.6	1.1	−.0	−.2
7	47	3.6	2.7	.3	.3	65	78	1.7	1.8	+.2	−.2
8	47	3.6	2.7	.3	.2	66	78	2.0	1.6	−.0	−.2
9	47	4.4	3.1	.1	.3	67	78	.1	0	−.2	−.1
10	47	3.8	2.3	.1	.0	68	78	3.2	0	−.0	−.2
11	47	3.6	3.1	.2	.4	69	78	4.4	2.7	+.2	−.1
12	47	4.1	2.0	.2	.3	70	78	.1	.1	−.0	−.2
13	47	3.8	3.0	.4	.2	71	78	0	.1	+.1	−.1
14	47	3.9	2.7	.1	.4	72	78	−.1	.1	+.1	−.1
15	47	3.3	2.8	0	1.7	73	78	2.6	0	0	1.9
16	48	3.9	3.2	0	.1	74	78	3.2	0	−.1	.8
17	48	4.3	2.8	.4	.1	75	78	3.2	0	.1	−.1
18	48	3.8	3.0	.1	1.3	76	78	3.0	0	.1	.3
19	49	4.3	2.4	.1	1.4	77	79	4.1	2.3	.3	2.6
20	49	4.0	2.8	.3	1.4	78	79	1.9	1.6	.2	1.6
21	49	4.1	2.9	.3	1.1	79	80	2.1	1.8	.2	1.6
22	49	3.9	2.7	.3	1.3	80	80	2.0	1.7	.4	1.7
23	49	4.9	3.1	0	1.2	81	80	2.0	1.7	.2	1.6
24	49	3.8	3.1	.3	1.2	82	80	2.1	1.6	.4	1.7
25	50	2.7	3.7	.0	0	83	80	2.2	.1	.3	1.5
26	50	2.3	2.8	1.4	.1	84	80	1.9	1.6	.2	1.6
27	50	2.6	3.3	1.0	0	85	80	1.9	1.7	.3	1.5
28	65	3.8	3.3	.2	.2	86	80	2.1	1.6	.3	1.7
29	65	.5	.1	.2	0	87	80	1.8	1.7	.4	1.5
30	65	4.6	3.1	.1	−.1	88	80	1.9	1.6	.2	1.5
31	65	4.2	.2	.1	.3	89	80	1.9	1.4	.4	1.8
32	65	4.5	2.3	3.2	.1	90	80	1.5	1.6	.2	1.5
33	65	.3	.2	.1	.1	91	81	2.3	2.7	.1	−.2
34	65	4.6	3.4	.2	.2	92	81	2.3	.1	.1	.1
35	65	3.6	0	.1	.3	93	81	1.7	3.0	.1	−.1
36	65	4.3	2.4	3.0	.1	94	81	−.1	2.9	0	−.1
37	65	2.7	0	.2	.1	95	81	2.5	2.8	2.6	−.3
38	65	.3	.1	.2	.2	96	81	.7	2.3	.1	−.1
39	65	2.0	0	.1	.3	97	81	2.1	1.4	−.1	−.2
40	65	4.0	.1	0		98	81	2.3	2.8	2.5	−.2
41	65	3.7	.1	.1		99	81	2.2	3.1	0	0
42	65	0	.2	0		100	81	1.6	3.1	0	.1
43	65	3.4	.1	0	0	101	88	3.4	.2	.1	.8
44	65	3.5	.1	0	−.1	102	88	3.2	1.9	0	1.1
45	65	3.5	0	−.1	0	103	88	4.5	2.1	.2	.8
46	65	3.0	0	0	0	104	88	4.8	2.4	0	−.1
47	65	3.4	0	0	0	105	88	3.6	.4	.2	.8
48	65	3.8	.1	0	0	106	88	2.9	2.2	.1	.3
49	65	3.4	.1	0	0	107	88	3.2	.5	.3	.6
50	65	.1	0	0	0	108	88	2.8	1.0	.1	.1
51	66	1.8	2.0	−.1	.1	109	89	.2	1.2	0	0
52	66	3.8	.3	.4	−.1	110	89	2.4	1.6	.2	−.1
53	66	4.9	3.3	.2	.1	111	89	2.7	−.1	.1	−.1
54	66	3.8	.3	.2	.1	112	89	0	−.2	.1	0
55	66	3.7	.1	.1	0	113	89	2.7	1.7	0	.4
56	66	5.4	3.2	.2	0	114	89	2.5	1.4	.1	.1
57	74	0	.1	−.0	−.1	115	89	2.7	.7	0	−.1
58	74	4.1	2.4	+.2	−.1	116	89	3.1	−.1	.1	−.1

ing lactose and raffinose but not dextrose. This is highly unusual since dextrose as the simplest sugar is almost always fermented before any other carbohydrate. We have hesitated however to give a name to this type while it is characterized by only 10 cultures.

TABLE 6.

STREPTOCOCCI ISOLATED FROM HORSE-DUNG.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	32	4.6	1.1	.8	1.9	51	46	.9	0	.1	0
2	35	1.4	1.3	.2	.3	52	46	0	.6	0	−.1
3	36	2.0	0	0	.1	53	46	1.9	.2	0	−.2
4	36	1.3	.2	0	0	54	46	1.9	−.2	0	0
5	36	1.7	.1	0	.1	55	47	2.2	2.7	.1	.1
6	36	2.1	0	.3	0	56	47	1.3	0	.1	0
7	36	.4	0	.2	0	57	47	1.0	0	0	0
8	36	2.1	0	.3	.1	58	47	2.1	−.1	0	−.1
9	36	1.0	0	0	0	59	47	1.6	−.1	0	0
10	36	.8	.6	.1	.2	60	47	1.6	.1	.2	0
11	37	2.6	0	2.8	.2	61	47	1.7	0	.1	−.1
12	37	1.1	.2	0	0	62	47	1.2	−.1	0	−.1
13	37	1.8	0	0	0	63	47	.2	−.1	−.1	0
14	37	1.0	0	.5	.3	64	47	2.4	−.1	0	−.1
15	37	2.3	0	.2	.1	65	47	2.3	.1	.2	0
16	37	2.3	0	.3	.1	66	47	2.5	0	0	1.2
17	37	1.0	0	.3	0	67	47	2.4	.1	0	0
18	37	.6	0	0	0	68	48	.2	−.4	.2	−.1
19	37	2.3	0	0	0	69	48	1.1	.3	−.1	0
20	37	2.5	0	0	.1	70	48	.1	0	.1	−.1
21	37	1.4	0	0	.1	71	48	1.5	−.2	0	−.3
22	37	1.5	0	0	0	72	48	2.2	−.3	0	−.2
23	37	1.6	0	0	.1	73	48	1.0	0	.1	−.1
24	37	1.8	1.6	0	0	74	48	2.0	0	−.1	−.1
25	38	.2	.2	0	0	75	48	1.5	.2	0	−.1
26	38	0	0	0	0	76	48	1.0	0	0	0
27	38	2.1	0	0	.3	77	48	1.8	−.1	0	0
28	38	1.4	0	.5	.1	78	48	−.1	0	0	−.1
29	38	1.5	0	.3	0	79	64	1.1	.1	0	0
30	38	1.9	0	.3	.1	80	64	1.3	0	0	.1
31	38	2.1	0	.5	0	81	82	1.0	.1	.1	.1
32	38	1.3	0	.2	.3	82	82	.8	0	0	−.1
33	38	2.0	.3	1.7	.1	83	82	1.1	0	.1	.1
34	38	2.3	0	0	0	84	82	.9	.1	.4	.1
35	38	.2	0	0	0	85	82	.8	.1	.1	0
36	38	1.0	0	0	0	86	82	.9	.1	.1	0
37	38	2.5	0	0	0	87	82	.8	0	.1	.1
38	38	2.1	0	.3	.1	88	82	1.4	.8	.2	.1
39	39	.3	.2	.3	.2	89	82	1.8	.6	.2	.1
40	39	.4	0	0	.2	90	82	1.2	−.1	.1	−.1
41	39	2.1	0	0	.1	91	82	.9	.1	0	.1
42	39	2.3	.1	0	0	92	82	1.1	0	.2	.1
43	39	1.8	.1	0	.2	93	82	.9	.1	.1	−.1
44	39	0	0	.3	.2	94	82	.8	.1	.1	0
45	39	0	0	.3	.1	95	82	.2	−.1	0	.1
46	39	0	0	.4	0	96	82	.8	.1	0	.1
47	39	1.3	0	.2	0	97	82	1.2	.1	0	.1
48	39	1.6	0	0	.1	98	82	1.1	.1	−.1	0
49	39	.2	0	0	0	99	87	.9	0	−.1	−.1
50	39	2.0	.3	2.0	0	100	87	1.0	0	0	0

CONCLUSIONS.

The general result of our investigations has been to confirm and extend the conclusions of the English bacteriologists. We have found, as Andrewes and Horder concluded from their analysis of

Houston's descriptions, that the chief types of streptococci in the normal human intestine are Strept. mitis, fermenting dextrose and lactose, and Strept. fecalis, fermenting dextrose, lactose, and mannit. In addition we would call attention to the presence of a peculiarly vigorous type of Strept. equinus fermenting dextrose only.

TABLE 7.
STREPTOCOCCI ISOLATED FROM COW-DUNG.

No.	Sample No.	Percentage of Acid Formed				No.	Sample No.	Percentage of Acid Formed			
		Dextrose	Lactose	Raffinose	Mannit			Dextrose	Lactose	Raffinose	Mannit
1	41	2.1	2.6	0	0	44	69	3.0	.2	0	0
2	41	.6	0	0	0	45	69	0	.1	.1	.1
3	43	2.7	2.5	.1	0	46	69	.1	0	0	.1
4	44	3.4	3.4	1.2	.1	47	69	0	.2	0	0
5	44	2.0	2.2	0	0	48	69	2.0	2.0	0	0
6	44	2.1	2.1	0	.1	49	69	2.5	.2	.1	0
7	44	2.3	2.1	0	0	50	69	.2	.1	0	0
8	44	.2	3.0	2.6	0	51	69	2.5	.1	−.1	.1
9	53	2.3	2.4	2.0	0	52	69	0	2.0	0	0
10	53	0	3.1	2.0	0	53	69	2.5	1.7	−.1	0
11	53	4.1	2.9	0	.8	54	69	.1	.3	.1	0
12	54	2.2	2.6	1.7	0	55	69	.1	.1	0	0
13	54	2.1	2.6	2.0	.1	56	69	2.2	.1	−.1	0
14	54	−.1	−.2	−.1	−.1	57	70	2.5	−.1	.1	.1
15	54	−.1	2.9	−.1	0	58	71	2.3	0	.2	.1
16	54	0	3.1	2.6	−.1	59	71	2.5	0	0	−.1
17	54	−.2	3.0	2.3	1	60	71	2.4	−.1	.1	0
18	54	−.1	2.8	2.3	0	61	71	.1	−.1	.2	−.1
19	54	−.1	2.9	2.4	.1	62	71	2.5	−.1	.1	0
20	54	3.1	2.7	−.1	.1	63	71	2.8	0	.1	0
21	54	−.2	2.8	−.1	0	64	71	2.0	0	.1	−.1
22	54	3.3	3.0	.1	−.2	65	72	3.0	1.6	.2	.1
23	56	2.1	−.1	2.1	0	66	72	.3	−.1	0	−.1
24	56	3.7	2.8	−.1	1.4	67	72	3.3	−.1	0	.2
25	56	2.4	2.5	2.3	−.1	68	72	2.6	2.0	.1	−.1
26	56	0	2.9	2.5	.2	69	72	2.5	−.1	.1	.1
27	56	−.1	3.1	2.4	.1	70	72	2.4	.1	2.6	0
28	56	−.1	2.3	2.3	.1	71	72	2.2	−.2	.1	0
29	56	4.2	3.1	2.0	1.3	72	72	0	0	.0	0
30	56	0	2.9	2.3	0	73	72	2.2	0	.1	.2
31	56	3.5	2.0	2.5	−.1	74	72	1.9	−.1	.1	.1
32	59	3.5	2.0	0	.1	75	75	4.1	2.7	.2	0
33	61	3.5	2.0	0	0	76	77	3.7	.6	.1	−.1
34	61	4.2	3.1	0	.1	77	86	1.0	0	.1	.1
35	61	3.0	3.2	3.5	0	78	91	−.2	.1	.1	.1
36	61	3.0	3.5	0	0	79	91	.1	0	.2	.2
37	67	2.0	.2	0	0	80	92	2.3	1.6	1.4	1.3
38	67	1.1	.2	0	0	81	92	2.2	1.9	1.5	.0
39	68	.4	0	.1	0	82	92	.1	0	.1	.2
40	68	2.8	.2	−.1	0	83	96	.2	0	.2	0
41	68	2.6	.1	0	0	84	96	1.7	1.2	2.3	1
42	68	0	2.3	−.1	0	85	98	2.8	2.6	3.0	0
43	69	2.0	0	0	.1	86	97	.3	0	0	−.1

We have found, as Andrewes and Horder did, that the characteristic streptococcus of the horse is the non-lactose-fermenting Strept. equinus; and this appears to be the only form typically present. Seventy-three per cent of all our equine strains belonged clearly to this type.

In the feces of the cow, on the other hand, streptococci which fail to ferment lactose are relatively less common, as Houston showed. Strept. equinus is present; but so are Strept. mitis and Strept. salivarius (fermenting dextrose, lactose, and raffinose); and we have found in small numbers a peculiar new type fermenting lactose and raffinose but not dextrose. Strept. fecalis, as in the horse, is absent.

From the standpoint of the water bacteriologist several conclusions may be drawn. In the first place, it appears that pollution with road washings may be distinguished from wastes of other sorts by a study of the streptococci present. Since most of the pollution in street washings comes from horse-dung, and since lactose-fermenting streptococci are comparatively rare in such deposits, a test for these organisms should have distinct value. Such a test might easily be made by inoculating tubes of lactose broth, incubating for several days, and then plating on lactose agar.

The distinction between human and bovine pollution is also promising. There are three points of difference which seem to deserve investigation. First the presence of streptococci forming over 3.5 per cent of acid in dextrose broth would seem in general to be characteristic of human stools. Second, raffinose-fermenting forms (Strept. salivarius) appear to be more abundant in bovine than in human feces. Third, and of most importance, mannit-fermenting streptococci (Strept. fecalis), which make up about one-quarter of the human streptococci, are very rare in the feces of the horse and cow. In this respect Houston's results and our own are in complete agreement; and the use of mannit broth as a differential test for streptococci of human origin would seem sufficiently promising to warrant further study.

REFERENCES.

ANDREWES, F. W., AND HORDER, T. J. 1906. "A Study of the Streptococci Pathogenic for Man," *Lancet*, 171, p. 708.

BETTENCOURT, A., AND BORGES, I. 1908*a*. "Recherches sur le B. coli des vertébrés inférieurs et des céréales," *Archivos do Real Instituto Bacteriologico Camera Pestana*, 2, Fasc. II, p. 221.

BETTENCOURT, A., AND BORGES, I. 1908*b*. "Peut-on distinguer le colibacille de l'homme de celui des animaux au moyen de la fixation du complément," *Archivos do Real Instituto Bacteriologico Camara Pestana*, 2, Fasc. II, p. 245.

FERREIRA, A., HORTA, A., AND PARADES, C. 1908. "Recherches sur le B. coli communis de l'intestin de l'homme," *Archivos do Real Instituto Bacteriologico Camara Pestana*, 2, Fasc. II, p. 153.

GORDON, M. H. 1904. "Report on a Bacterial Test for Estimating Pollution of Air," Supplement to the *Thirty-second Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1902–3, p. 421.

GORDON, M. H. 1905. "Report of Some Characters by which Various Streptococci and Staphylococci May Be Differentiated and Identified," Supplement to the *Thirty-third Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1903–4, p. 388.

HOUSTON, A. C. 1905. "The Bacteriological Examination of Milk," *Report to the London County Council*, July 11, 1905.

HOUSTON, A. C. 1906. "Report on the Bacteriological Examination of (1) Deep Well Waters; (2) Upland Waters; and (3) Cow-Dung," Supplement to the *Thirty-fourth Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1904–5, p. 326.

MACNEAL, W. J., LATZER, L. L., AND KERR, J. E. 1909. "The Fecal Bacteria of Healthy Men," *Jour. Infect. Dis.*, 6, p. 123.

WINSLOW, C.-E. A. AND A. R. 1908. *The Systematic Relationships of the Coccaceae.* New York.

AN INVESTIGATION OF THE EXTENT OF THE BACTERIAL POLLUTION OF THE ATMOSPHERE BY MOUTH SPRAY.*

C.-E. A. Winslow and E. A. Robinson.

(From the Biological Laboratories of the Massachusetts Institute of Technology.)

INTRODUCTION.

With the progress of exact knowledge sanitarians have been led to place less and less emphasis upon the part played by the atmosphere in the spread of zymotic disease. Bacteriological studies have shown that quietly expired air is germ free and epidemiological investigations indicate that little place is left for aerial transfer of disease in any form (Chapin, 1908). Even sewer air has been shown by recent work to be on the whole remarkably free from pollution with sewage bacteria.

On the other hand, Horrocks and Andrewes in England have demonstrated that a local pollution of sewer air does occur in the presence of mechanical splashing, taking the form of a fine spray of sewage, temporarily suspended in the air. Similarly, the work of Flügge and his pupils has shown that in sneezing, coughing, and loud speaking a spray is thrown out which contaminates the air for a considerable distance with bacteria from the mouth. It has been generally assumed that this mouth spray may be an important factor in the spread of tuberculosis, and other diseases affecting the respiratory tract.

The real importance of the mouth spray, as of any other vehicle of disease, can be properly determined only by quantitative investigations. The day of qualitative sanitation is fast passing. Not, "Is such a thing dangerous?" but, "How dangerous is it?" is the question we ought to ask. Applying this criterion to the bacterial content of sewer gas one of the writers has been led to the conclusion that on the whole the danger of infection from that medium is very slight (Winslow, 1909). In the present investigation the attempt has been made to apply similar quantitative standards to the mouth spray, and to determine whether the extent of air pollution with mouth bacteria under normal conditions is sufficient to be measured bacteriologically and to be estimated as a practical factor in the spread of zymotic disease.

---

* Received for publication October 22, 1909.

PREVIOUS INVESTIGATIONS ON THE DISCHARGE OF BACTERIA IN MOUTH SPRAY.

It is particularly to Flügge and his pupils that we owe the most careful studies of the possibilities of aerial transmission of disease germs, either in the form of dust or in the form of fine spray (Flügge, 1897*a* and 1897*b*). He was the first to lay special stress upon the danger from the spray produced in coughing in the case of tuberculosis (Flügge, 1899), and to point out how much more important this danger is than the possibility that the disease may spread through the blowing about of dried sputum which before this time had been accepted on the basis of Cornet's classic work (Cornet, 1889) as the principal mode of disseminating the disease.

TABLE 1.

DISTRIBUTION OF BACTERIA BY MODERATELY LOUD SPEAKING.
Laschtschenko (1899).
Room, 90 cu.m. Speaking for 1 hour.

Distance of plate from speaker. Meters	0.5	0.75	1.0	1.25	1.5	1.75
Total plates exposed	1	3	1	2	3	2
Negative plates	0	0	0	0	0	0
Mean number B. prodigiosus per plate	450	32	10	6	4	8

TABLE 2.

DISTRIBUTION OF BACTERIA BY LOUD SPEAKING (ONE HOUR).
Laschtschenko (1899).

	Mean Number B. prodigiosus per Plate					
Distance. Meters	1	2	3	4	5	6
Small room (50 cu. m.)	1	3	2	0	1	1
Large room (90 cu. m.)	5	10	..	3	..	..

The first important experiments upon mouth spray were carried out by Laschtschenko, and upon them Flügge's earlier papers were largely based, altho the full results were not published until two years later (Laschtschenko, 1899). The general method employed in these experiments consisted in inoculating the mouth with a heavy suspension of B. prodigiosus in normal salt solution and then causing the subject to cough, sneeze, or speak loudly for a specified length of time. Agar plates were exposed at various distances to receive any bacteria which might settle upon them. Some of the experiments were made in a glass chamber of 3.2 cubic meters capacity provided with an opening for the mouth of the investigator; others were carried out in rooms of 50 and 90 cubic meters capacity.

Quiet speaking, in the glass chamber, showed a few colonies; in the larger room, none. The results for moderately loud speaking and for loud speaking we have tabulated for convenient reference in Tables 1 and 2.

A general summary of all the loud and moderately loud speaking experiments grouped together is given in Table 3.

Coughing and sneezing of course gave higher results which need not be considered in detail. Sneezing distributed the infection for nine meters.

The most significant of Laschtschenko's experiments were carried out with tuberculous patients. The coughing of such a patient while sitting for an hour in the glass chamber, to which reference has been made, distributed virulent tubercle bacilli, as evidenced by animal tests made with normal salt solution exposed in the chamber during the test. The actual extent of the air pollution was however slight, as shown by drawing off the air of the chamber, filtering, and injecting into guinea-pigs. When less than 2 cu.m. of air per hour were examined, no positive results were obtained; but out of five tests covering a period of five hours each, and involving the filtering of 10 cu.m. of air in each case, two tests showed virulent tubercle bacilli.

Hübener (1898) carried out a series of similar experiments with a view to the danger of infecting patients upon the operating table from the mouth. His method consisted in exposing four agar plates about 50 cm. in front of and below the face of a subject who had infected his mouth with B. prodigiosus. In 11 experiments in which the subject counted aloud for 10 minutes the number of colonies on the four plates varied from 101 to 1,507 and averaged 458; two tests with three or four coughs gave 223 and 265 colonies and in two tests a single sneeze gave an uncountable number.

TABLE 3.

GENERAL SUMMARY OF LASCHTSCHENKO'S EXPERIMENTS.

	90 cu.m. Room	50 cu.m. Room
Total plates	24	12
Mean number B. prodigiosus per plate	25	1.5
Per cent of negative plates	8	33

Along similar lines, Hamilton (1905) has shown that streptococci are expelled from the mouth in coughing, speaking, and even forcible breathing, and has emphasized the danger of surgical infection from this source.

V. Weismayr (1898) obtained somewhat different results which indicated a more restricted distribution of mouth spray than that reported by other observers. He found B. prodigiosus on plates directly in front of a coughing subject in quiet air up to a distance of 4 meters, but not beyond and not out of the zone directly in front of the mouth. When the air of the room was agitated, however, he found small numbers of bacilli 1–2 meters behind and at the side of the subject. In speaking experiments infection could not be traced at distances over 1 meter. Slides exposed before the mouths of coughing consumptives showed tubercle bacilli only rarely.

The most exhaustive of all the experimental studies of the spread of B. prodigiosus in mouth spray was perhaps that carried out by Koeniger (1900). He followed in the main the methods of Laschtschenko, making in all 18 speaking experiments in two rooms, one of 97, the other of 440 cu.m. capacity. His main results have been summarized in Table 4.

Koeniger observed also the amount of infected spray discharged by enunciating various letters and showed that consonants like *p* and *t* caused the greatest pollution. The amount of spray of course increased with loudness and sharpness of speech but, as indicated in the table below, whispering, with its clear enunciation, gave higher results than gentle speech in an ordinary tone.

TABLE 4.

DISTRIBUTION OF BACTERIA IN MOUTH SPRAY.

(Koeniger, 1900.)

Speaking, generally for 15 minutes.

	Tone of Voice				
	Sharp	Loud	Moderately Loud	Soft	Whisper
Total plates	30	101	143	23	24
Mean number B. prodigiosus per plate	14.5	7.8	2.1	1.4	5.3
Total negative plates	0	9	91	16	10
Per cent negative plates	0	8.9	63.6	69.6	41.7

Koeniger found B. prodigiosus on his plates in all parts of the room, at extreme distances of 12.4 meters in front of the speaker and at one side of and behind him. In this respect his results differ from those of v. Weismayr. On the other hand, he made important observations on the length of time for which the bacilli would remain in the air which contradict Flügge's conclusion, based on experiments with atomizer spray, that bacteria from the mouth might remain suspended in the air for 4 or 5 hrs. Koeniger's general results are brought together in the table below. B. prodigiosus was never found in quiet air an hour after the speaking had ceased, tho when the air of the room was agitated by moving about and opening and shutting doors, positive results were obtained after an hour and a half.

TABLE 5.

SETTLING OUT OF MOUTH SPRAY IN QUIET AIR.

(Koeniger, 1900.)

Interval between Speaking and Exposure of Plates. Minutes	Percentage of Colonies Found, Taking Number on Plates Exposed during Speaking as 100
0	95
10	38
20	9.8
30	5.5
45	2.7
60	0.7
90	0.0
105	9.6*
120	0.0
150	0.0

* Air agitated.

Experiments with B. mycoides made in similar fashion showed a much more limited distribution of mouth spray than was observed in the case of B. prodigiosus. Out of 105 plates exposed during 15 minutes' speaking only 23 showed colonies of the specific germ. The average number of colonies per plate was 7 and the maximum distance 3 meters. All plates exposed 10 minutes after speaking were sterile.

Gordon in England was the next to take up this work and his investigations confirmed in all respects the work of Laschtschenko and Koeniger (Gordon, 1904). Repeating the B. prodigiosus experiments he traced aerial infection for 12.2 meters in front of the subject and for 3.7 meters behind him. We have summarized these particular experiments in Table 6 below. Gordon's most important contribution to the whole subject lay in the suggestion that the mouth streptococcus might be used as a normal index of mouth pollution without the use of artificial B. prodigiosus inoculations; but this aspect of his work will be considered farther on.

Mention may perhaps be made here of experiments by Flügge (1897), Buchner, Megele, and Rapp (1899), and Hutchison (1901), which have shown, as might be expected, that bacteria artificially sprayed into the air can be transported by air currents of low velocity for considerable distances. Buchner, Megele, and Rapp found a limiting velocity of 1 mm. per second for B. prodigiosus and 1.3–1.8 mm. per second for yeast cells 3–10 microns in diameter. Little can be learned from such experiments as to the behavior of the mouth spray itself which may be in a much grosser state of division.

So far reference has been made for the most part only to experiments in which B. prodigiosus was used as an indicator of the distribution of bacteria in the mouth spray. Another important series of investigations has dealt more directly with the practical question of the spread of tuberculosis by observations of the behavior of the tubercle bacillus itself. Laschtschenko's work along this line has already been discussed. At about the same time Englemann (1898) and Heymann (1899) showed that tubercle bacilli could be detected on plates of various sorts exposed within 0.5–1 meter of coughing consumptives; and Heymann succeeded in infecting 6 out of 25 guinea-pigs exposed 20–45 cm. in front of coughing consumptives, with heads fixed toward the patients.

TABLE 6.

DISTRIBUTION OF BACTERIA IN MOUTH SPRAY.
(Gordon, 1904.)
Generally, loud speaking for 1 hour.

Total plates exposed	30
Mean number B. prodigiosus per plate	0.7*
Total negative plates	14
Per cent negative plates	47

* Number on four positive plates not stated.

Fränkel (1899) found that out of 219 masks worn by tuberculous patients 52 showed macroscopic evidence of contamination with sputum; in 26 of the latter tubercle bacilli could be demonstrated by staining. Fourteen patients wore the masks in these experiments. Two yielded positive results almost always, one frequently, 3 once each, and 8 never showed tubercle bacilli on the masks.

In a later investigation, Heymann (1901) shut up a coughing consumptive patient in a small chamber for an hour or two. At the close of this period the patient left the chamber and broth plates were exposed, after the chamber had remained quiet, for varying periods, 15, 30, or 90 minutes. Of 24 guinea-pigs inoculated with broth thus exposed, two which had received broth exposed 30 minutes after the end of the coughing developed tuberculosis. In a second series of tests the air in the chamber was drawn off and washed, and the sediment in the washings centrifuged and injected. Of 14 guinea-pigs injected with the sediment from 7 cu.m. of air drawn off while the coughing was in progress only two became infected; of 22 guinea-pigs injected with the sediment from 11 cu.m. of air drawn off at periods of 15–60 minutes after the coughing stopped, all remained sound. Many more recent observers have shown that tubercle bacilli may be found on plates exposed before coughing consumptives. The most exhaustive of these investigations is perhaps that of Ziesché (1907). He arranged a late having an area of 324 square centimeters at a distance of 40–80 cm. mouth of phthisical patients and counted under the microscope the number le bacilli discharged in half an hour. Of the patients examined only once cent gave positive results; of those frequently examined, 78.9 per cent. er 29 out of 62 tests were positive. Of the 29 positive plates, 3 showed less bacilli, 15 from 10 to 100, 7 from 100 to 500, 2 from 500 to 1,000, one 1,445, 20,174 bacilli.

ilar observations have been made in the case of leprosy. Schäffer (1898) eprosy bacilli on glass plates exposed before the mouth of a leper after 10 reading. Plates near the mouth showed many thousands of bacilli and in- ould be traced to a distance of 1.5 meters. These experiments were repeated firmed by Hübener (1898) in a paper to which reference has been made

is sufficiently clear from a consideration of all these investiga- hat bacteria may indeed be discharged from the mouth in such as to spread disease. On the other hand it seems equally from the tuberculosis experiments that the practical danger nfined to a local discharge of spray rather close to the mouth of atient. Rightly interpreted there is no basis in any of this for the conclusion that disease is spread broadcast through the sphere. Professor Flügge's own treatment of the matter is cial and conservative. He lays stress only on coughing, not on speaking, as a possible danger. He points out that in experiments carried out by his pupils tubercle bacilli were abundant only within 0.5 meter of the coughing patient and that beyond 1.5 meters their number was so small as to make the chance of infection practically nil. He notes that only certain phthisical patients discharge infected spray when they cough and that others do so only at certain periods of the disease, and only at certain times of day. In one of his first papers (Flügge, 1897*b*), he says: "Altogether it appears that under natural conditions the infection resulting from sputum spray is not so significant as one might think at first sight." In a later paper (Flügge, 1901) the following rational rule is laid down: "During strong paroxysms of coughing, the consumptive should keep at arm's length from his companions and should hold a handkerchief before his mouth. In workrooms, offices, and such places the space between the heads of the workers should be at least 1 meter."

No exception can be taken to such conclusions as these. Unfortunately, however, others have not been so conservative. The experim subject lagiosus experiments particularly have lent themselves to misleading interpretations. It is common to see statements to the effect that bacteria are discharged from the mouth in coughing, sneezing, and even loud speaking to distances of 12 meters and in all directions behind as well as in front of the subject; and from such unqualified statements the inference is implicitly drawn that a general infection of the atmosphere takes place over a wide radius and that there is real danger of infection from breathing the air in the neighborhood of a consumptive. Fränkel (1899) early took up an extreme position, speaking of spread through the air as the "most frequent cause of tuberculosis," and recommended the wearing of masks by tuberculosis patients discharging bacilli freely. This was ten years ago, it is true; but Tendeloo (1908) at the last Tuberculosis Congress said: "It has been proved by numerous experiments (Cornet, Flügge, etc.), that bacteria floating in the air, either in dry dust particles, or suspended in minute fluid particles, may be inhaled into the bronchi, bronchioli, and air-vesicles, where they fall down just like inhaled dust particles;" Pannwitz (1908) said: "If they contain a coughing tuberculous patient, inclosed spaces, such as dwelling-houses, workshops, counting-rooms, public halls, railway coaches, and steamer cabins, are speedily converted into tuberculosis-inhalatoriums in which healthy persons may infect themselves;" and Bernheim (1908) recommended the wholesale disinfection of air on the ground that "there is an intimate relation between tuberculosis and the microbes of the air. The more highly the atmosphere is charged with bacteria the greater is the number of consumptives living in that unhealthy environment."

As a matter of fact it can be shown that even the B. prodigiosus experiments do not indicate any general atmospheric infection in the proper meaning of the term; and studies of the discharge of tubercle bacilli and of normal mouth bacteria show that the spread of these organisms is insignificant in comparison with the discharge of B. prodigiosus in culture media with which the mouth has been artificially infected.

REPETITION OF EUROPEAN EXPERIMENTS ON AIR POLLUTION BY MOUTH SPRAY USING B. PRODIGIOSUS AS A TEST ORGANISM.

The first object of our own experiments was to extend and place on a quantitative basis the work of Flügge's pupils on air pollution mouth spray. It was necessary therefore to follow their procedure rather closely, using B. prodigiosus as a test organism and checking it by the simple exposure of plates, in order to be sure that con ns of their work were fairly duplicated. At the same time we examined measured volumes of air and determined the actual nu r of specific germs present by methods discussed in the succeeding section.

T ee methods were employed in our experiments for inoculating mouth with B. prodigiosus. The first was to pour water on an ar slant culture, shake so as to get a s ion, rinse out the mouth with the suspension for a minute, and r the surplus water. The second was to transfer the organisms tly from the culture to the mouth by means of a platinum loop. The third was to transfer the bacteria on a loop to a small quantity of water (1 or 2 c.c.) which could be entirely retained in the mouth. The last method proved t satisfactory. Analyses of the saliva at the close of the experiments generally showed that B. prodigiosus was present in 10^{-6} c.c.

In the first 10 experiments the subject read from a book in a loud tone and at a fairly rapid rate. Beginning with Experiment 11 and continuing through the series the subject repeated from memory verses in English and German, in a loud tone and with exaggerated enunciation. The discarding of the book appeared to facilitate the spread of bacteria.

The tests were carried out in three laboratories of the Institute of Technology. Two of them are about 6×8 meters in area and 3.7 meters high; the third is 11×8 meters and 3.7 high. In the qualitative work ordinary plates were exposed in different parts of the rooms at varying heights and at varying distances from the speaker. The speaking usually lasted for 15 minutes and the plates were exposed during this time and for a varying period, generally three-quarters of an hour afterward. The speaking was done by four different subjects during the course of the experiments.

The general results obtained by the simple exposure of Petri plates are indicated in Table 7. The speaking was continued for 15 minutes in each case except in Experiments 14 (7 minutes), 15 (13 minutes), and 21 and 23 (10 minutes).

It will be noticed that the substitution of speaking for reading,

TABLE 7.

B. PRODIGIOSUS ON PLATES EXPOSED IN ROOM POLLUTED BY MOUTH SPRAY.

EXPERIMENT	PERIOD OF EXPOSURE MINUTES	NUMBER OF PLATES	TOTAL COLONIES	MEAN PER PLATE	NEGATIVE PLATES	
					Total Number	Percentage
7	15	11	1	.09	10	91
8	15	12	2	.16	11	92
9	15	18	2	.11	16	89
10	15	21	4	.19	17	81
11	75	25	22	.88	14	56
12	15-75	42	3	.07	39	93
13	75	24	22	.92	10	42
14	..	25	9	.36	18	72
15	75	25	20	.80	16	64
16	135	13	34	2.6	3	23
17	..	11	68	6.2	3	27
18	45	10	134	13.4	0	0
19	60	12	88	7.3	0	0
20	60	14	75	5.4	0	0
21	60	14	142	10.1	0	0
22	75	12	56	4.7	4	33
23	25-70	36	98	2.7	8	22
Totals and averages		325	780	2.4	169	52

at and after Experiment 11, caused an increase in positive results and that as the later experiments progressed the number of bacteria on the plates continued to increase, perhaps as a result of more thorough inoculation of the mouth or more vigorous enunciation. Control plates, 22 in number, exposed just before Experiments 19 and 20, were all negative, showing that no serious permanent pollution of the room air had taken place.

In general these results agree closely with those obtained by the German and English observers cited earlier in the paper. The more important data are presented for comparison in Table 8.

TABLE 8.

COMPARATIVE RESULTS OF VARIOUS OBSERVERS ON EXPOSURE OF PLATES IN ROOMS POLLUTED BY MOUTH SPRAY.

Observer	Total Plates Exposed	B. prodigiosus. Mean Colonies per Plate	Percentage of Negative Plates
Laschtschenko	36	17.2	17
Koeniger	521	5.8	39
Gordon	30	0.7	47
Winslow and Robinson	325	2.4	52

Laschtschenko's figures are a little high; but with that exception the results are entirely concordant. It is clear that loud speaking discharges bacteria from the mouth in the form of spray; and that by inoculating the mouth of the speaker with B. prodigiosus and

ng plates in the room the specific germ may be detected in con
le numbers.

estive data in regard to the distribution of the mouth spray e may be obtained by analyzing the results of our experi- ccording to the distance of the plates from the position of the . The results for each point at which ten or more plates were d in different experiments are brought together in Table 9. aviest pollution appears to be between 2 meters and 4.5 meters he speaker. The spray from the mouth probably shoots over which are too near; and the particles which are carried beyond eters are fewer in number.

TABLE 9.

B. Prodigiosus on Plates Exposed at Various Distances from the Speaker.

Distance Meters	Total Plates	Total Colonies	Colonies per Plate
1.0	13	2	.15
1.5	28	62	2.21
2.0	48	190	3.96
2.5	22	126	5.73
3.5	50	208	4.16
4.5	13	40	3.08
5.5	33	61	1.85
7.0	24	50	2.08
7.5	31	42	1.35

Some idea of the general extent of superficial pollution due to mouth spray may be gained from the following considerations. In the room used for all the plate experiments except 7, 9, and 12, 254 plates were exposed and 774 colonies of B. prodigiosus developed, an average of 3.5 colonies per plate. The total area of the room was 480.000 sq.c. and the mean area of a plate 54.5 sq.c. Assuming that all the organisms above a plate settled upon it, the mean number of B. prodigiosus in the whole room in each experiment would be $\frac{480.000 \times 3.5}{54.5}$ or 30.830, and the number discharged on a square meter of surface (by 15 minutes' speaking) would be 640.

QUANTITATIVE METHODS OF ENUMERATING BACTERIA IN THE AIR.

The various processes suggested for enumerating bacteria in the air may be classified broadly under two main heads, filtration methods and sedimentation methods. In one case a measured volume of air is filtered through a powdered solid medium (asbestos, salt, sugar, sodium sulphate, cotton, sand, glass wool) or is bubbled through a liquid. The solid filtering medium is washed in sterile water and aliquot portions of the water are plated; or portions of the liquid through which the air has been bubbled are plated directly. In all these procedures there is some danger that bacteria may be lost if the medium is not of sufficient fineness, or if the passage of the air is too rapid or if the connections of the apparatus are not all tight. The proper collection of samples with a fine filter on the other hand is time consuming.

The second group of methods involves the exposure of surfaces of nutrient media upon which the bacteria from a known volume of air may settle out and on incubation develop colonies. In its most primitive form ordinary Petri plates are left open in a room for known periods of time. The objection to this is twofold. In the first place the bacteria which fall upon the plates are not related to any determinable quantity of air. In the second place their number will vary greatly with the effect of chance air currents. Hesse long ago founded a more exact method upon this general principle by drawing air slowly through a long cylindrical tube lined with nutrient medium. Recently an improvement on this procedure has been suggested by one of us (Winslow, 1908) involving the use of two liter-and-a-half bottles, having gelatin on the bottom. The bottles are joined by tubing in tandem and a liter of air is drawn in by another water-suction bottle and the bacteria allowed to settle out. The chief objection to this procedure lies in the cumbrousness of the apparatus which requires the carrying about of two large bottles for every sample to be examined. For investigations in the laboratory, however, this procedure has many advantages.

In the present study three methods have been used. Most of the determinations were made by the culture bottle method; and in connection with this procedure two methods of collecting samples have been tried, one the usual method of drawing in air by connecting the second culture bottle with a water-aspirator, the other a vacuum method like that used in collecting air samples for carbon dioxide. In this case the culture bottle is first prepared by covering the bottom with gelatin, plugging with cotton, and sterilizing. At the same time a number of vaselined one-hole rubber stoppers plugged with three-inch lengths of capillary tubing are separately sterilized in a pipette case. If the bottles were sterilized with the rubber stoppers in them the breakage would be heavy; but after sterilization the stoppers may be substituted for the cotton plugs. Each bottle is then attached by the capillary tube to a suction pump and the air is exhausted for about 10 minutes or until a 90–95 per cent vacuum has been obtained. The capillary tube is now sealed in a flame and the sample of air may be taken at any time by removing the stopper. The danger of leakage from imperfectly fitting stoppers is considerable in this method and many bottles must be discarded but there is a great saving of time in sampling.

Another method used in a few determinations is a simple modification of the plate method designed to secure quantitative results with protection from air currents. An ordinary plate is opened and a covered cylinder a little larger than the plate and about 20 cm. high is placed over it. The apparatus is allowed to stand for half an hour so that the bacteria may settle. Finally in some of the later experiments with mouth bacteria the sand filter method was used, air being drawn by means of a suction bottle through a tandem filter, each member holding a 1.5 cm. layer of sand passing a sieve with 100 meshes to the inch.

QUANTITATIVE STUDY OF AIR POLLUTION BY MOUTH SPRAY USING B. PRODIGIOSUS AS A TEST ORGANSIM.

There are two objections to the method of exposing Petri plates as a measure of true air pollution. In the first place the procedure is necessarily an inaccurate one since the number of bacteria settling is conditioned not only by the number present in the air but also by the amount of motion in the atmosphere. In a strong current of air the plate method must yield results which are relatively too low. On the other hand in quiet air with heavy particles falling through it the results of the plate method must be too high. In the special case with which we are concerned the loud speaking, coughing, or sneezing produces a fine rain which falls more or less rapidly during the period of actual speaking and for a short time afterward. The rate of fall for small falling bodies may be approximately determined from Stoke's law which for spheres of density 1, calling the density of air .00018 and calling g 980, reduces to the form

$$v = 1{,}200{,}000 r^2$$

where v is in centimeters per second and r is the radius of the falling particle in centimeters. An ordinary bacterium with a radius of about 0.0001 cm. should therefore fall through quiet air at a rate a little under 0.012 cm. per second, or about 17 inches per hour. If single isolated bacteria were discharged in the mouth spray their fall would be slow and would go on for several hours. As a matter of fact however such is not the case, as is made clear by Koeniger's experiments which have been cited above. He found that 60 per cent of the bacteria in the mouth spray disappeared from the air in 10 minutes, while after 20 minutes less than 10 per cent of the original number remained.

In two of our experiments similar data were obtained by opening all the plates before the speaking but removing some of them after various intervals. The results as shown below indicate no increase in bacteria after the actual period of speaking itself.

TABLE 10.

DURATION OF AIR POLLUTION BY MOUTH SPRAY.

Total B. prodigiosus on plates.

Period of exposure after speaking. Minutes	0	15	30	60
Experiment 12	1	2	..	0
Experiment 23	..	36	34	28

Clearly the mouth spray is a fairly coarse rain which settles out for the most part in 15 or 20 minutes. With such a rain as this the exposure of plates must give an exaggerated idea of the bacterial content of the air. Everything from the air above falls on the plates; but a liter of air should be credited only with the bacteria which it contains at a given moment. Many, even of these, cannot fairly be considered as constituting real aerial pollution if they are in large droplets, for such droplets would be too heavy to be drawn into the mouth with the inspired air.

In order to distinguish between coarse rain falling through the air and finer mist suspended in it, for a period of some minutes at least, we made quantitative determinations by the culture bottle method in Experiments 2, 5, and 6 and in Experiments 15–23, and by the covered plate method in Experiments 7, 8, 22, and 23. In the first three experiments the samples were collected during the speaking by another person. In the last nine the samples were collected just after the aking by another person, or by the speaker himself with carefully shed hands. The results of the culture bottle tests are shown in ble 11 below.

TABLE 11.

QUANTITATIVE POLLUTION OF ATMOSPHERE BY MOUTH SPRAY.

Experiment	Duration of Speaking Minutes	Mean Colonies per Plate Exposed at Same Time	Number of Liter Samples	Number of Samples Showing B. prodigiosus
[illegible]	[illegible]	..	5	0
[illegible]	[illegible]	..	3	0
[illegible]	[illegible]	..	9	0
[illegible]	[illegible]	0.8	8	0
[illegible]	[illegible]	2.6	5	0
[illegible]	[illegible]	0.2	3	0
[illegible]	[illegible]	13.4	11	1
[illegible]	[illegible]	7.3	8	0
[illegible]	[illegible]	5.4	8	0
[illegible]	[illegible]	10.1	10	2
[illegible]	[illegible]	4.7	16	0
[illegible]	[illegible]	2.4	19	0
Totals			105	3

Examinations were made by the covered plate method described above in Experiments 7, 8, 22, and 23. Immediately after the close of the speaking the plates were opened and covered with the cylinders which were allowed to stand 30 minutes for the bacteria present to settle. This period is theoretically too short but as a matter of fact the results as shown in Table 12 below were higher than those obtained by the culture bottle method.

TABLE 12.

AIR POLLUTION BY MOUTH SPRAY MEASURED BY COVERED PLATE METHOD.

Experiment	Duration of Speaking Minutes	Mean Colonies per Plate Exposed at Same Time	Number of Samples	Mean Volume of Air Inclosed	B. prodigiosus Found
7	[illegible]	[illegible]	10	840	0
8	[illegible]	[illegible]	11	840	0
22	[illegible]	[illegible]	7	1,370	2
23	[illegible]	[illegible]	7	1,370	2
Totals and averages			35	1,050	4

Altogether taking both quantitative methods into account 140 liters of air were examined and B. prodigiosus was found seven times. The four positive tests with the covered plate were obtained at points about 2 meters in front of the speaker. Two of the positive culture bottles were at the extreme end of the room, nearly 7 meters from the speaker; the other was at a distance of more than 5 meters. These last results were obtained in the two experiments out of the whole series (see Table 11) which gave the largest number of colonies on the plates.

GORDON'S SPECIFIC TEST FOR AIR POLLUTION.

There is one weak point in all experiments involving an artificial inoculation of the mouth. We have no certainty that the bacterial emulsion introduced in this way behaves as the normal or pathological fluids of the mouth would do. It seems highly probable that a liquid with which the mouth has but just been rinsed would be ejected more freely than the sputum itself. In fact Heymann (1899) and Ziesché (1907) were able to show that in the mouth spray of a consumptive there are several distinct types of droplets which can be distinguished under the microscope and that it is only in droplets derived directly from the bronchi with but little admixture of mouth saliva that the tubercle bacilli are abundantly present. Some more direct test of normal mouth pollution than that furnished by the B. prodigiosus experiments is therefore greatly to be desired.

The real desideratum in the bacterial examination of air is a test which shall quantitatively detect the presence of some normal mouth bacterium which might serve as an index of mouth pollution as the colon bacillus serves in water analysis as an index of intestinal pollution. Such an index has been suggested by Gordon (1904), but its value has not been confirmed by subsequent investigations so far as we are aware. Gordon pointed out that one of the commonest organisms in the saliva is a streptococcus which he called Strept. brevis and which has since been more fully described by Andrewes and Horder (1906) as Strept. salivarius. It is a short chained form which renders broth uniformly turbid, clots milk, reduces neutral red, and ferments saccharose, lactose, and raffinose. Gordon found streptococci capable of fermenting lactose present in from one-millionth to one-hundred-millionth of a cubic centimenter of saliva. Similar streptococci which fail to ferment lactose or ferment neutral red were found to be present in ordinary street air but lactose-fermenting streptococci were absent. Gordon examined 10 samples of 50 liters of street air for streptococci by bubbling it through salt solution which was later mixt with nutrient broth. He found a lactose-fermenting streptococcus only once.

On the other hand, he found that the mouth streptococci could be easily detected in rooms polluted by mouth spray. His method consisted in exposing plates 3.5–5 inches in diameter containing neutral red broth, which was later incubated under anaerobic conditions. In a small room, 4.7 by 4.0 meters in area, 2 out of 6 plates showed mouth streptococci after 15 minutes' loud speaking, 4 out of 6 showed them after half an hour's speaking, and in 5 separate experiments after one hour of speaking 22 out of 30 plates gave positive results. In a larger room, 14.9 by 11.6 meters, 11 out of 34 plates and 28 out of 40 plates were positive after one hour's loud speaking. Quiet speaking and reading yielded negative results. These results coincide closely with those of the German experiments. Like them they measure the superficial discharge of spray but give no clear idea of the quantitative distribution of bacteria in the air above.

QUANTITATIVE STUDY OF AIR POLLUTION BY MOUTH SPRAY USING THE PRESENCE OF MOUTH STREPTOCOCCI AS AN INDEX.

Our final experiments were devoted to the examination of air polluted by mouth spray with a view of determining to what extent the mouth streptococci can be detected in the air itself by ordinary quantatitive methods.

In the first test of this sort the air was examined by the culture bottle method, lactose broth being used in the bottles instead of gelatin. The bottles were placed on a table directly in front of the speaker and from 0.6 to 2.4 meters away. In the first half of the work the speaker's mouth was 0.7 meters above the table and in the second half 1.2 meters above. Five liters of air were first examined for controls. Then the subject orated for 20 minutes, 4 liters of air being examined after each five-minute period. None of the 16 samples showed lactose-fermenting streptococci.

In the second and third experiments the air was examined by the sand filter method. In the second experiment, five different subjects orated loudly for a period of 10 minutes apiece (one taking part twice, so that six samples of air were examined). While the speaking by each subject was going on a sample of 4.5 liters of air was collected by attaching a water aspirator to a tandem sand filter placed between 0.9 and 1.5 meters away from the speaker and directly in front of him. Each filter in the pair held a layer 1.5 cm. deep of sand which had passed a sieve having 100 meshes to the inch (finer than 0.25 mm.). After collecting the sample the sand was poured into bent dextrose broth tubes and incubated for four days at 37°. Litmus lactose agar plates were made from the broth tubes which showed growth. No lactose-fermenting streptococci were found in any case so that the 27 liters of air examined in this experiment were again all negative.

The third experiment was similar to the second, except that conditions were more severe. Seven tests were made, with two different subjects. The speaking was in English and German and was loud with very vigorous enunciation. In two tests the speaking was interspersed with considerable coughing. Samples of 4.5 liters each were collected during each period of speaking (10 minutes) from a point 35 cm. away from the speaker's mouth and 15 cm. below it. The sand was incubated in dextrose broth for a week, and litmus-lactose plates were inoculated at intervals from the broth tubes. No lactose-fermenting streptococci were found in this examination of 31 liters of air.

Altogether 74 liters of air exposed to pollution by mouth spray were examined by these quantitative methods for mouth streptococci with uniformly negative results. From these experiments it appears, as might be expected, that the pollution of the atmosphere by normal mouth streptococci is considerably less than the contamination with B. prodigiosus after inoculating the mouth with that organism.

Gordon's experiments, made with plates exposed during an hour's reading, of course constituted a very severe test since the plates received all the heavy spray which fell through the air during that period. We made a final experiment along similar lines to his, using litmus lactose agar instead of broth. Eight plates were exposed 45 cm. below and 45 cm. in front of the mouth of the speaker and eight others 15 cm. below and 15 cm. in front. In all these cases the speaking was loud, and vociferous, in English and German, and the period of exposure was five minutes. Finally four plates were exposed 15 cm. in front of and 15 cm. below the mouth of the speaker who orated and coughed for three minutes.

The plates were incubated for four days and subcultures were made from all suspicious colonies. All showed large colony counts to 1,200). Of the first eight plates exposed to spray from speaking 5 cm. away, one only showed a single colony of the acid-forming streptococci. Of the eight plates exposed to spray from speaking 15 cm. in front of and 15 cm. below the mouth, three gave positive results. Two of the plates showed each a single colony, the third was wholly reddened so that the number of acid colonies could not be exactly determined. The streptococcus colonies were not in isolated pure cultures but in mixt colonies each of which was obviously derived from a droplet of saliva containing many forms. Of the 16 plates examined in these two series three were overgrown with an alkalin spreader which might have obscured any streptococci present. Finally of the four plates exposed to the spray from coughing at a distance of only 15 cm. from the mouth, two were overgrown with alkalin spreaders and so may be excluded from consideration. Of the other two one showed two droplet colonies and the other four. All six on cultivation showed the presence of mouth streptococci.

Altogether it appears from these experiments with the mouth streptococci that normal mouth bacteria are much less easily discharged into the air than are artificial cultures introduced into the mouth. Loud speaking and even coughing did not deposit very large numbers of mouth streptococci even upon plates within 15 cm. of the mouth; and the quantitative examination of 74 liters of air exposed to the spray from loud and vigorous speaking at distances of 35 cm. to 2.4 meters from the mouth failed to show the presence of mouth streptococci in any instance.

SUMMARY AND CONCLUSIONS.

It appears from these experiments, as it appeared in the German investigations which have been reviewed above, that bacteria with which the mouth has been inoculated are discharged in the act of speaking in large numbers, and to considerable distances. Positive results were obtained as far as 7.5 meters from the speaker; and the average number of bacteria discharged over the whole surface of a room (6×8 meters) by 15 minutes' loud speaking was 646 per square meter. These results coincide closely with those obtained by Laschtschenko, Koeniger, and Gordon. A still more extensive spread of mouth spray would of course result from coughing and sneezing.

Most of the particles in the mouth spray are rather coarse and settle out rapidly. In fact the spray is like rain falling through the air, rather than mist suspended in it. Koeniger showed that 60 per cent of the bacteria in the mouth spray disappeared from the air in 10 minutes, while after 20 minutes less than 10 per cent of the original number remained. In estimating aerial infection proper, it is the bacteria suspended in the air which are important because these only could be inhaled with the inspired air. Our second object was to attain a quantitative measure of the extent of such aerial infection; and we found that after inoculating the mouth with a rich culture of B. prodigiosus and speaking loudly and with vigorous enunciation for 15 minutes only seven colonies of the specific germ could be obtained from 140 liters of air collected at the close of the speaking from various points in front of the speaker. The true aerial infection is therefore relatively small by comparison with the distribution of the heavier particles of spray.

Experiments with fresh cultures introduced in large amounts upon the surfaces of the mouth give an exaggerated idea of the quantitative importance of the mouth spray. We therefore attempted finally to control the investigation by a study of the distribution of the mouth streptococci which had been suggested by Gordon as offering a promising test of normal mouth pollution. Gordon easily detected these organisms by exposing plates after speaking for various lengths of time. We found them on plates by similar methods; but even at a distance of only 15 cm. from the mouth of a subject who coughed for three minutes the number of droplets containing mouth streptococci was small. Quantitative tests of the air itself from points 35 cm. to 2.4 meters in front of speakers who spoke vigorously in English or German failed to show any mouth streptococci in 74 liters of air examined.

It might be surmised that in pathological conditions bacteria may be more readily dislodged from the mucous membranes than would be the case under normal conditions. Thus the mouth streptococcus may furnish too low an index for measuring the mouth spray, as the B. prodigiosus furnishes too high a one. Experiments carried out with coughing consumptives by Laschtschenko and Heymann, how-bear out the conclusion that the actual extent of air infection is small. Out of five air samples of 10 cu.m. each examined by tschenko only two contained tubercle bacilli; out of seven pies of 1 cu.m. each, examined by Heymann, only two gave posi- esults.

It is not intended to minimize the real danger from mouth spray. ge numbers of bacilli are discharged in coughing by some consumptive patients. Ziesché found in one case 20,000 tubercle bacilli on a glass plate 324 sq.cm. in area exposed for half an hour from 40–80 cm. in front of the mouth of a phthisical patient. The infection by mouth spray of food or [illegible] ts later brought directly or indirectly in contact with the [illegible] al and important danger. Flügge's practical recommendati [illegible] ly warranted by all the facts: "During strong paroxysms [illegible] ghing, the consumptive should keep at arm's length from his companions and should hold a handkerchief before his mouth. In wo [illegible] rooms, offices, and such places the space between the heads of th [illegible] orkers should be at least 1 meter."

On the other hand all this furnishes no basis for a belief that tuberculosis or any other disease is contracted to an appreciable extent through the inspired air. The mouth spray is a fairly coarse rain which quickly settles downward. Even in artificial experiments with B. prodigiosus the actual extent of air pollution, when quantitatively measured, appears to be small; and when infection by normal mouth streptococci or tubercle bacilli is studied it is much smaller still.

These conclusions are in harmony with the conviction now generally gaining ground that aerial infection of any sort is a minor factor in the spread of zymotic disease; and in regard to tuberculosis they accord well with the opinion that ingestion rather than inhalation is the principal channel of infection even in the case of bacilli originally discharged through the air in the form of mouth spray.

REFERENCES.

Bernheim, S. 1908. "Relations de l'air avec la tuberculose; sterilisation de l'air," *Transactions of the Sixth International Congress on Tuberculosis*, I, Part 1, p. 172.

Buchner, H., Megele, L., and Rapp, R. 1899. "Zur Kenntnis der Luftinfection," *Archiv f. Hyg.*, 36, p. 235.

Chapin, C. V. 1908. "Air Infection of Minor Importance," *Jour. Amer. Med. Assoc.*, 51, p. 2048.

Cornet, G. 1889. "Die Verbreitung der Tuberculose ausserhalb des Körpers," *Ztschr. f. Hyg.*, 5, p. 192.

Flügge, C. 1897*a*. "Ueber Luftinfection," *Ztschr. f. Hyg.*, 25, p. 179.

Flügge, C. 1897*b*. "Ueber die nächsten Aufgaben zur Erforschung der Verbreitungsweise der Phthise," *Deut. med. Wchnschr.*, 23, p. 665.

Flügge, C. 1899. "Die Verbreitung der Phthise durch staubförmiges Sputum und durch beim Husten verspritzte Tröpfchen," *Ztschr. f. Hyg.*, 30, p. 107.

Flügge, C. 1901. "Weitere Beiträge zur Verbreitungsweise und Bekämpfung der Phthise," *Ztschr. f. Hyg.*, 38, p. 1.

Fränkel, B. 1899. "Zur Prophylaxe der Tuberculose," *Berl. klin. Wchnschr.*, 36, p. 21.

Gordon, M. H. 1904. "Report on a Bacterial Test for Estimating Pollution of Air," Supplement to the *Thirty-second Annual Report* of the Local Government Board containing the "Report of the Medical Officer" for 1902–3, p. 421.

Hamilton, A. 1905. "Dissemination of Streptococci through Invisible Sputum," *Jour. Amer. Med. Assoc.*, 44, p. 1108.

Heymann, B. 1899. "Ueber die Ausstreuung infectiöser Tröpfchen beim Husten der Phthisiker," *Ztschr. f. Hyg.*, 30, p. 139.

Heymann, B. 1901. "Versuche über die Verbreitung der Phthise durch ausgehustete Tröpfchen und durch trockenen Sputumstaub," *Ztschr. f. Hyg.*, 38, p. 21.

Hübener, W. 1898. "Ueber die Möglichkeit der Wundinfection vom Munde aus und ihre Verhütung durch Operationsmasken," *Ztschr. f. Hyg.*, 28, p. 348.

Hutchison, R. F. 1901. "Die Verbreitung von Keimen durch gewöhnliche Luftströme," *Ztschr. f. Hyg.*, 36, p. 223.

Koeniger, H. 1900. "Untersuchungen über die Frage der Tröpfcheninfection," *Ztschr. f. Hyg.*, 34, p. 119.

Laschtschenko. 1899. "Ueber Luftinfection durch beim Husten, Niesen und Sprechen verspritzte Tröpfchen," *Ztschr. f. Hyg.*, 30, p. 125.

Pannwitz, G. 1908. "Social Life and Tuberculosis," *Sixth International Congress on Tuberculosis*, special volume containing a series of public lectures specially prepared for the congress, p. 49.

Schäffer. 1898. "Ueber die Verbreitung der Leprabacillen von den oberen Luftwegen aus," *Archiv f. Derm. und Syphilis*, 44 (Festschrift gewidmet Filipp Josef Pick, II), p. 159.

Tendeloo, N. P. 1908. "On the Channels of Infection in Primary Pulmonary Tuberculosis," *Transactions of the Sixth International Congress on Tuberculosis*, I, Part 1, p. 86.

V. Weismayr, A. R. 1898. "Zur Frage der Verbreitung der Tuberculose," *Wien. klin. Wchnschr.*, 11, p. 1039.

Winslow, C.-E. A. 1908. "A New Method of Enumerating Bacteria in Air," *Science*, N. S., 28, p. 28.

Winslow, C.-E. A. 1909. "The Sanitary Significance of Bacteria in the Air of Drains and Sewers," *Report* of the Sanitary Committee to the National Association of the Master Plumbers of the United States for 1907–1908–1909.

Ziesché, H. 1907. "Ueber die quantitativen Verhältnisse der Tröpfchenausstreuung durch hustende Phthisiker," *Ztschr. f. Hyg.*, 57, p. 50.

[Authorized reprint from Vol. XXVII, No. 2 (April, 1910), of the Copyrighted PROCEEDINGS OF THE ENGINEERS' CLUB OF PHILADELPHIA.]

THE DISINFECTION OF WATER AND SEWAGE.

EARLE B. PHELPS.
(Visitor.)

Read January 15, 1910.

THE subject of disinfection of drinking-waters and of sewage is in no sense a new one. Almost as early as the nature of infectious diseases and the methods of their communication became known, through the developments of modern bacteriology, the desirability of disinfecting waters in particular was recognized. Attention was first drawn to the practical possibility of such processes through the work of early investigators in connection with the water-supplies of troops in the field. Without going into details of these investigations, it will suffice for our present purposes to note that many disinfecting processes were developed by workers in England, Germany, and France. These processes depended, in the main, upon the application of prepared pellets of the various disinfectants employed, and in general involved the addition first of the disinfectant itself, and later of one or more neutralizing compounds, by which the active disinfectant was destroyed and harmless chemical products alone remained in the water. Compounds of chlorin, bromin, and iodin, copper salts, permanganate, and many other powerful disinfectants were employed in this way. On the whole, remarkably successful results for the purpose in hand were attained, but the processes were necessarily limited to small volumes of water, and were totally unsuited, owing to the nature of the reactions and the cost of the material employed, for application to large city supplies; consequently for many years attempts to purify domestic water-supplies have been confined in the main to sand filtration methods which are now so well known that their discussion at this time is uncalled for. It may be pointed out that these processes are in reality disinfecting processes, since in most cases their chief aim is the removal of pathogenic germs. In the course of the rapid and well-nigh universal development of filtration processes, however, the basic principle of chemical sterilization has never been completely lost sight of. Great stimulus was given to these ideas about a decade ago by the development of commercial processes for the production of ozone. The well-known germicidal properties of this oxygen compound, coupled with the fact that its end-product is ordinary atmospheric oxygen, make the process an ideal one from a chemical and physiological point of view. Commercially, it has always been hampered by the relative high cost of production, by mechanical deficiencies in the machinery necessary for such production, and by certain physical difficulties attendant upon the introduction of the ozone into the water. Therefore, despite the fact that progress in the ozonization of water has been consistent and quite rapid, yet the use of ozone in water disinfection has not become general. It must be particularly noted, however, that the deficiencies of this process are purely mechanical, and that the work of investigation which is going on in many parts of the world may reasonably be expected eventually to develop a process as successful commercially as it is ideal from purely sanitary considerations.

Quite early in the history of the chemical disinfection of water the possibilities of chlorin compounds were recognized. Electrolytic processes for the manufacture of these compounds were developed as early as in 1889, when Webster in England and Woolf in this country attempted the use of electrolyzed sea-water solutions in disinfection work of one kind or another. Here again mechanical difficulties were met with which, combined with the fairly high cost of production, prevented the general adoption of these methods. The commercial production of calcium hypochlorite or bleaching powder had in the meantime been developed to so high a degree of efficiency, owing to the great commercial demand for this product, that sanitarians soon had at their command an extremely efficient disinfectant which could be obtained in any desired quantity at very moderate cost. Attention therefore was early directed to the possibilities of this commercial product, particularly in connection with sewage disinfection. As early as 1854, the Royal Sewage Commission of Great Britain recommended the use of this substance in deodorizing the sewage of London. In 1885 the Special Committee of the American Public Health Association carried out an exhaustive study of all available disinfecting materials, and found that hypochlorites in general were the most efficient substance that could be used, cost being considered. In Germany, at the Hamburg Hygienic Institute, the work of Proskauer and Elsner in 1897, and later of Dunbar and his associates in 1904 and 1905, demonstrated anew the possibilities of hypochlorite of calcium in sewage work, with special reference to disinfection rather than to mere deodorization. At the Royal Testing Station at Berlin work carried out in 1906 confirmed the Hamburg results, and indicated that the disinfection of sewage by this means was entirely feasible. Rideal's experiments at Guilford, England, made about the same time, practically confirmed the German results.

All of these investigations, and more particularly those made in Germany, had reference to the emergency use of chemical disinfection during epidemics, especially of cholera. In such situations questions of economy do not usually arise, and, with their usual thoroughness, the German experts established standards of purification so high that their processes, although eminently satisfactory under the conditions for which they were devised, were still too costly for ordinary every-day use. It remained for the investigators of this country to demonstrate that much lower percentage efficiencies than those obtained previously would still suffice in routine work, and that the cost of obtaining these sufficiently satisfactory results would not be prohibitive. These conclusions were first reached as a result of investigations carried out at the Sanitary Research Laboratory of the Massachusetts Institute of Technology, with which the writer has the privilege to be associated. These studies, which were begun in 1906 and extended over a period of two years, were made possible by the generous co-operation and financial assistance of the United States Geological Survey. They were shortly followed by studies made by Kellerman, Pratt, and Kimberly for the United States Department of Agriculture and the Ohio State Board of Health. The first practical demonstration of the use of bleaching powder on a large scale was made by the State Sewage Commission of New Jersey at Red Bank, under the speaker's supervision. The work was started in October, 1906, and carried on during the fall and a portion of the following summer. Two hundred and fifty gallons of sewage per day were treated at this place. About this same time the writer was retained by the Baltimore Sewage Commission to carry on experiments at Baltimore looking toward the disinfection of the final effluent of the proposed trickling filters now being built at that place. Since that time numerous investigations have been made in all parts of this country, and many working plants have been installed or are now in process of installation. Without exception, the conclusions of the early Massachusetts experiments have been confirmed, and for the first time in the history of chemical disinfection, it has been amply demonstrated that sewage may be thoroughly disinfected at a cost which is not disproportionate to the cost of other purification processes.

Briefly, then, this is the history of the development of chemical disinfection. At the present time the most serious problem is not how to disinfect sewage or water, but rather under what conditions such disinfection is called for, just what the process accomplishes and under what amount of supervision it must be carried out. There is grave danger that, through ignorance of the essential aims and actual accomplishments of this process, it will be misused or employed in situations where its use is uncalled for. Therefore this opportunity to explain the particular work which the process may be expected to accomplish, the peculiar conditions under which it may be properly applied, and its severe limitations, as a general method of sewage treatment, is especially welcome. It must be pointed out at the very outset, and will be reiterated throughout the course of this paper, that the chemical disinfection of sewage or of water is not a panacea. Except under strictly limited and peculiar local conditions it is not even a substitute for other purification methods. In general, it may best be described as an "adjunct," or, to use a term familiar to engineers, "a factor of safety." To the extension and development of this idea, and to a discussion of the actual place of disinfection in sewage and water work, these remarks will be chiefly addressed.

The recent revival of active interest in the possibility of chemical disinfection took place, first, in the field of sewage disposal, and later spread to water purification. It may be well to maintain this order of development, and to consider first the chemical disinfection of sewage and of sewage filter effluents.

DISINFECTION OF SEWAGE.

Sewage consists of about 999 parts of pure water and 1 part of impurity, about one-half of which is organic impurity and bacterial life. Sewage disposal deals with this five one-hundredths per cent. A perfect process of sewage disposal may be defined as one which totally removes and finally oxidizes to a mineral form this very small proportion of organic matter. The slow sand filter, developed to its highest degree of efficiency, can be relied upon under specially favorable conditions to practically accomplish this result. It is possible to produce by such means a water fit for domestic purposes.

The cost of such treatment is high even under the most favorable circumstances, where, as in the case of the Massachusetts towns, large areas of suitable sandy soil are readily available. In less fortunately situated locations, and always among the larger cities, the cost of such a process would be prohibitive. Therefore the tendency of the times as illustrated by the work of experiment stations, and by the effort of municipalities along these lines, has been toward more rapid and less perfect processes. Unfortunately along with this tendency there has come another tendency, namely, toward the standardization of processes, by which is meant a tendency toward the adoption of certain settled types of works regardless of the local requirements. This is a result in part of the unwillingness, and at times the inability, of communities to undertake special investigations of their own or to employ expert assistance. It results also in part from the unfortunate disposition of certain of our State authorities to demand this kind of uniformity throughout their jurisdiction. We have therefore a situation which might be amusing if it were not so serious, in which a designing engineer learns by experience that any plan submitted by him in certain jurisdictions will not receive the necessary sanction of the proper State officials unless certain standard features are incorporated; whereas he is equally well aware that in a neighboring State no plan will be approved which embodies these same standard features. The fact cannot be too strongly emphasized that the solution of any particular sewage disposal problem is one which depends mainly upon the requirements of the local situation. The only conceivable general solution of the problem would be perfect purification, such as has already been defined, and even if this were desirable the result might be obtained by two or more different methods. In general, such purification is unnecessary, and insistence upon it would be a grievous mistake. If partial purification methods are to be allowed, then surely they must be adapted to the requirements in each case. Therefore your attention is first directed to the nuisance which lack of sewage disposal may bring about in order that the method of abatement may be indicated.

One serious nuisance which may follow the introduction of crude sewage into a body of water is the deposit of solid material. Such material we describe as "suspended matter" in the sewage, and one of the classes of treatment to which attention is most often directed has in view the removal of suspended matter from the sewage and the prevention of this form of nuisance. Obviously, now, if the stream is swift and the dilution large, or if the discharge be made into rapidly moving tidal currents, this nuisance will not occur, and special treatment for its abatement will be unnecessary and unwise. Under reverse conditions of discharge into slowly moving streams, particularly into streams which are dammed, or bodies of water which are shallow and do not possess strong tidal currents, the possibility of deposit upon the bottom is one which must be dealt with, and the removal of suspended matter from the sewage must be accomplished to a greater or less degree.

The second kind of nuisance is that which results from the putrescible character of sewage, regardless of whether the organic matter is suspended or in true solution. This is the property of sewage matter by which it robs a stream of its available oxygen, and consequently of its power of self-purification. Under these conditions fish life is destroyed, noxious odors arise from the water, and the stream becomes virtually an open sewer rather than merely a polluted water. The line between these two conditions is a distinct one. The capacity of any stream to absorb sewage and maintain its own aëration is limited and calculable. If this capacity is exhausted, a very definite change in the character of the water occurs and the conditions above outlined result. The treatment of these conditions must be very different from that outlined in the first case. The question of suspended matter may or may not be a factor, but in this case the organic matter must first be oxidized and rendered stable or non-putrescible. The process of oxidation may go on independently of, or in connection with, any other processes, according as one or more of these classes of nuisances is possible.

The third special class of nuisance, and one which refers to public health rather than to public convenience, is the ever present possibility that pathogenic bacteria may be contained in the sewage. The extent of this danger need not be argued, nor is it desirable at this time to take up the somewhat debatable question of the efficiency of our ordinary sewage purification processes in destroying such bacteria. Somewhat divided opinions upon this question are held. The most exhaustive study of the problem that has yet been made was carried out by Houston under the auspices of the Royal Sewage Commission of Great Britain, as a result of which it was concluded that "the biological processes at work in the filters were not strongly inimical, if hostile at all, to the viability of pathogenic germs." It is the speaker's opinion, based upon all the available evidence and upon a long personal experience with investigations of this character, that the removal of pathogenic germs by rapid filtration methods is not greater than would be accomplished naturally in the streams in an equal period of time. That such removal is considerable is frankly admitted. In the course of a few hours or of a day, under natural stream conditions, great improvement is always noted. This improvement, however, has not been sufficient to prevent the disastrous typhoid fever epidemics of Lawrence, Mass., Butler, Pa., Ithaca, N. Y., and other places too numerous to mention. If, therefore, there be any danger in the possible discharge of pathogenic germs into the stream in question, this danger must be considered by itself, and distinctly apart from the possible nuisances already mentioned. It is upon the solution of this particular problem that chemical disinfection directly bears. Whether or not nuisance may arise from the discharge of suspended matter or from the discharge of putrescible matter will determine the type of purification process necessary; whether or not it is desirable to prevent the possible discharge of pathogenic germs into the stream will determine, and must alone determine, the advisability of disinfecting the sewage or the treated effluent.

Emphasis has been laid upon these few general principles, because curiously we are better advised at the present day as to the methods of disinfection than we are as to its necessity. As has been previously stated, there is more danger that the possibility of disinfection will be misunderstood and that processes will be used as a substitute for other essential processes than that it will not be employed when necessary. The various methods of chemical disinfection which have from time to time been proposed have been fully described in another place, and need not be referred to here in detail. Suffice it to say that the application of commercial bleaching powder has been found to be by far the most efficient and practical process, and that such application has now been developed to such a point that its cost is not at all out of keeping with the benefits to be derived.

Bleaching powder is an impure commercial product manufactured in large quantities abroad by some of the earlier chemical methods, and in this country at Niagara by modern electrolytic methods. Owing to the fact that in the latter case it is essentially a by-product of the much more important caustic soda industry, its present market price is very low, and in fact less than the cost of production on a small scale. Upon admixture with water it goes into solution only partially; a residue of carbonate of lime and an excess of free lime remaining in the tank as a white sludge. In practice it is desirable at larger works to keep this mixture stirred up and to discharge the sludge with the solution; at smaller works economy indicates the use of the clear solution and the disposal of the lime sludge in a convenient manner. To the layman one of the most striking features of this process is the relatively small amount of disinfectant necessary. For crude sewage an amount of so-called "available chlorin" equivalent to about five parts per million parts of sewage, which amounts to about 125 pounds of bleaching powder per million gallons, suffices. Upon the present market price of $25 per ton or less, it will be seen that the cost of bleaching powder necessary will be in the neighborhood of $1.70 per million gallons of sewage disinfected. By the use of the quantity indicated, disinfection is accomplished within a very few minutes, and storage periods of not over thirty minutes are ample. Sewage stronger than the average American sewage would require somewhat larger amounts than these indicated, but twice the quantity probably represents the maximum. For partially purified effluents, such as those resulting from trickling filters, lesser quantities are sufficient. At Baltimore three parts per million of available chlorin, or 75 pounds of bleaching powder per million gallons, were found effective in the disinfection of the trickling filter effluent. At Boston satisfactory disinfection of a similar effluent was accomplished through a period of six months by the application of three and a half parts of available chlorin. Effluents of a higher degree of purity can be disinfected with corresponding smaller amounts. The total cost of the processes, including interest charges and depreciation upon the necessary fixtures, labor, and other items, will range from $1.00 or less in the case of effluents to about $3.00 in the case of crude sewages. These details are given in the accompanying table. The results, which have been described as satisfactory, are numerically expressed by removals of the total bacteria, averaging 97 per cent. in the case of effluents and 99 per cent. or more in the case of crude sewage. In the former case the combined efficiency of the filter and the disinfection will bring the figure up to 99 per cent. or more. Special studies have also been made in this connection to show the probable effect upon typhoid fever germs as compared with the effect upon the total bacterial content. The indication has been that the former are affected to fully as great an extent as the latter. They are probably more completely removed.

ESTIMATES OF THE COST OF OPERATION OF A PLANT FOR DISINFECTING SEWAGE OR EFFLUENT WITH CHLORID OF LIME, BASED ON A CAPACITY OF 5,000,000 GALLONS A DAY.

Available Chlorin Parts per Million	Bleach Pounds per Mil. Gal. Applied	Time of Contact Hours	Cost per Million Gallons.					
			Fixed		Operating			Total.
			Storage Tanks	Other Fixed Charges	Bleaching Powder	Labor	Power	
1	25	5.0	$0 10	$0 02	$0.30	$0.10	..	$0.52
2	50	2.5	.05	.04	.60	.10		.79
3	75	1.6	.04	.05	.90	.10	$0.02	1.11
4	100	1 2	.03	.07	1.20	.10	.02	1.42
5	125	0.8	.03	.08	1 50	.10	.03	1.74
10	250	0 5	.02	.16	3 00	.15	.06	3.39
15	375	0.5	.02	.24	4.50	.20	.09	5.05

DISINFECTION OF WATER.

Considering now the application of these same methods to the water problem, it may be said in brief that the principles involved are identical. Whether or not the chemical disinfection of water is desirable in any given situation must be determined upon principles similar to those already laid down. If the result desired is the simple removal of germs, this process probably represents the cheapest and perhaps the most desirable one now available. The word "perhaps" is inserted here advisedly. The question of just how desirable this treatment may be is one which must be submitted eventually to the consumer who pays the bills. There is a popular objection to the addition of chemicals to drinking-water. This objection was raised most seriously against the use of alum, but has largely disappeared, as the use of alum has become more and more common and as no ill effects have been developed. However harmless certain chemicals may be considered in the minds of those best qualified to judge, and however ill directed popular clamor against their use, it must be admitted that it is a legitimate consideration to be dealt with. Whether or not actual harm will be done is one matter; whether or not the purchaser of the water desires to have small amounts of chemical substances added to his supply (especially if he is willing and able to pay for more expensive processes which do not involve the use of chemicals) is quite a distinct matter. Assuming, however, that, as in the case of alum, any feeling which may be developed at present will disappear in the course of time, it is certainly true that under certain circumstances the chemical disinfection of water may be used to great advantage. As in the case of sewage, so also in the case of water, special consideration must be given to the primary needs of the situation. Disinfection merely kills the germs; if this is all that is required, then disinfection is indicated; if the removal of organic matter from a water seriously polluted with sewage is deemed advisable, then some other process must be employed. If that process is efficient also in the removal of germs, disinfection is uncalled for. If that process, on the other hand, is insufficient, or if economy indicates that it may purposely be made insufficient,—through the use of high rates of filtration, for example,—then disinfection may be advantageously employed to supplement the imperfect process. The two great fields which are open to water disinfection are the treatment of a very slightly or only occasionally polluted supply by disinfection alone, and the treatment of a more seriously polluted supply by the present methods at highly increased rates and by subsequent disinfection. In the latter case disinfection will be found a valuable adjunct to overloaded mechanical filters. The limiting rates of operation on slow sand filters are determined largely by the organic content of the water and by consequent economy in the expensive cleaning processes. The limiting rates on mechanical filters, on the contrary, are practically determined by the necessity for obtaining bacterial purification. Therefore it is especially with reference to this latter type that disinfection will be found important.

Although, as has already been indicated, the chemical disinfection of water has been practised from time to time at various places, the first notably successful plant in this country at least, and the one which is directly responsible for the present favorable consideration which this process has acquired, was constructed and operated early in 1908 by Mr. George A. Johnson, of New York city, at the Chicago stockyards. At this plant the highly polluted water of Bubbly Creek was treated first by chemical precipitation and then by means of bleaching powder. The results of this undertaking were highly satisfactory. Later Hering & Fuller, of New York city, of which firm Mr. Johnson is a member, were called upon to construct at Boonton, New Jersey, on the Jersey City water-supply, a plant for the complete disinfection of forty million gallons of water daily. This plant, which has been in operation since September, 1908, has been so fully described in various papers by Dr. Leal, who is primarily responsible for its installation, by Mr. Fuller, and by Mr. Johnson, that it will be unnecessary to discuss it in detail at this time. It is sufficient to note that the water in question is the somewhat polluted water of the Rockaway River, which has received the advantages of storage and sedimentation in its passage through the immense Boonton reservoir. The results of the continuous operation of this plant have been eminently satisfactory. It might be stated here that the recent litigation in connection with this plant had to do with certain contract requirements rather than with actual results achieved. In Mr. Johnson's report of the operation of the plant it is shown that the bacteria in the water before treatment ranged from a few hundred to a thousand or more, whereas after treatment the water was often found to be sterile, and contained, as a rule, not over ten bacteria per cubic centimeter. The bacillus coli was reported present almost uniformly in the raw water in 1 c.c. tests, and was seldom or never found in the treated water. Quantities of available chlorin not exceeding 0.3 part per million, or eight pounds of bleaching powder per million gallons of water treated, were found efficient. Mr. Johnson estimates the total cost of treatment, including additional labor required, at 14 cents per million gallons. The successful outcome of this great and novel undertaking has resulted in the introduction of this process in at least thirty localities in the eastern United States. The speaker has recently completed the installation and three months' study of a small plant used in connection with mechanical filters. Quantities of available chlorin ranging between 0.25 and 0.4 parts per million were found necessary, and results substantially like those already quoted were obtained, in spite of the fact that the raw water contained at times several thousand bacteria per cubic centimeter.

Here again, as in the case of sewage, the danger is that this process will be misused through a lack of understanding of its possibilities and its rightful field. It is not in general a substitute for filtration. It may be that filters are used where germ removal is all that is necessary. Such filters could be replaced by disinfection methods at an immense saving in the cost. A further danger, which is not so conspicuous in sewage work, lies in the use of this process by inexperienced persons. The proper regulation of the necessary amount of material does not require expert supervision at all times, but the question of how much disinfectant to employ in any given situation, and of the proper method of applying it, and other details of the operation, should in every case be submitted to expert judgment. In addition, the routine operation of the plant should be safeguarded in such a way that the possibility of mistakes should be minimized. As little responsibility and as little chance to go wrong as possible should be left to the operator. In other words, the operation should be made as nearly fool-proof as possible. With these safeguards properly applied, and under the conditions which have been outlined, it can safely be said that a new epoch in water purification methods has begun, and that the methods developed and introduced by Dr. Leal and Mr. Fuller, and especially by Mr. Johnson, have already established their rightful place in the ever growing field of water purification.

REFERENCES.

Sewage:

Proskauer and Elsner: Zeit. Hyg., vol. viii, 1890, p. 62.
Dunbar and Zirn: Vierteljahrsschr. ger. Med., vol. xvi, 1898, Suppl. Heft.
Dunbar and Korn: Ges. Ing., vol. xxvii, 1904.
Schumacher: Idem., 1905.
Schwarz: Ges. Ing., vol. xxix, 1906, p. 773.
Kranepuhl: Mitteilungen aus der Königlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. ix, 1907, p. 149.
Kurpjuweit: Idem., p. 162.
Rideal: Journ. Royal Sanitary Institute, vol. xxvi, p. 378.
Phelps, Earle B., & Carpenter, W. T.: Tech. Quart., vol. xix, 1906, p. 382. Contributions from the Sanitary Research Laboratory, vol. iv, 1908.
Kellerman, Pratt & Kimberly: Bull. 115, Bur. Plant Industry, U. S. Dept. Agr., 1907.
Phelps, Earle B.: The Disinfection of Sewage and Sewage Filter Effluents, U. S. Geol. Survey, Water Supply Paper 229, Washington, 1909.

Water:

Leal, Dr. John: Ann. Rep. Am. Water Works Assn., 1909.
Fuller, Geo. W.: Ibid.
Johnson, Geo. A.: Ibid.

DISCUSSION.

F. HERBERT SNOW (Harrisburg).—As you know, there is a Pennsylvania law enacted at the last legislative gathering which prohibits the use of alum and copper compounds in food-stuffs. It may be found under one of the sections of the Pure Food Act. The question of whether this law can be extended to apply to treated waters supplied for public uses is a mooted one. It has received some minor consideration, and was the subject of particular inquiry at the time the bill was before the legislative committee. I believe it was generally accepted that the bill if it became a law would not be applicable to mechanical filtration plants where the purification of the water is accomplished in part by the introduction of chemical solutions for the purpose of coagulation and precipitation. Nevertheless, there are occasional and persistent rumors that the law does in fact apply to water, and that alum, if found in water supplied for public uses, is administered contrary to the provisions of law.

It has come to be an accepted fact, generally speaking, that the use of alum compounds as a coagulant in the preliminary treatment of water is unattended with any possible danger to public health where the preparation of the chemical solutions and their introduction into the raw water is accomplished under the supervising direction of a competent person. Nevertheless, I believe that there are many water consumers throughout the towns of Pennsylvania who still adhere to the opinion that this use of alum is a menace to public health, and no amount of proof would convince some of them that this was not so. In fact, there have been known cases where the raw water was not capable of absorbing the chemical solution of alum compounds, and undoubtedly the solutions reached the homes of the consumers substantially in the forms in which they were introduced into the water, although highly diluted. To prevent such carelessness the Commissioner of Health has established a State supervision over all water purification plants in Pennsylvania.

The use of bleach in public water-supplies must bear to the public mind a relation similar to that of the use of alum. The State has discouraged the general application of chlorinated lime to drinking-water. However, in one instance, that of the city of Reading, the Commissioner has approved of the treatment of raw water with hypochlorites of lime under the skilled attention of the city's bacteriologist and chemist, pending the completion of a slow sand filter plant, which will be in operation possibly twelve months hence. Perhaps these few remarks are all that I ought to offer on the subject, in consideration of the position I now occupy. I came here to learn what Professor Phelps might have new to offer on the subject, since he is working in this field all the time. I might add that should you peruse the decrees of the Commissioner of Health relative to sewerage and sewage disposal since 1905, you would observe in the conditions and stipulations under which plans have been approved the provision, sometimes specifically stated, for the treatment of the effluent with some germicide. At Mt. Alto, where the State sanatorium for the treatment of tuberculosis patients has been built by Dr. Dixon and is now being operated, the effluent from the sewage works has been treated with a solution of bleach since the outset, with the result that not one sewage organism has been found in the final effluent.

George S. Webster.—It is hoped that the investigations of the use of disinfectants that have been carried on so extensively by Professor Phelps and his associates at the Massachusetts Institute of Technology will greatly simplify the problem of sewage purification, particularly in cities which have large streams of water near at hand. Any method which will tend to simplify the treatment of sewage will no doubt decrease the cost of disposal.

If the solids contained in the sewage can be removed mechanically and the bacterial life destroyed chemically by the addition of a solution of bleaching powder, and results obtained at a reasonable cost which will be acceptable, much has been accomplished to aid the profession in handling this important problem.

Geo. E. Datesman.—I do not know that I can say anything to add interest to the meeting, except that the city of Philadelphia has for the last nine months [illegible] as nearly as possible the working conditions [illegible] Such processes have been [illegible] has been [illegible] remain [illegible] completely [illegible] conditions [illegible] the other [illegible]

[illegible] in making our [illegible] amount of [illegible] Professor [illegible] has said: "There are certain [illegible] through small crevices [illegible] appearing as a white [illegible] I am quoting [illegible] less than two different [illegible] ingenuity of the engineer [illegible] accomplishment [illegible] and led to make [illegible] of the largest consulting engineering firm [illegible] suggestion and apply it to one of the [illegible] attack from platinum [illegible] which is attacked [illegible] large [illegible]

[illegible]

[illegible]

Our government and Board of Health investigations have decided that the bleach is quite the cheapest and most effective germicide. I trust that the investigations will be carried along until we become more positive in the methods of application and may know when to apply it in any method of sewage purification.

There is one other little matter: Professor Phelps says he does not advocate the application of bleach as a panacea or a substitute for other purification processes. He is very modest to make this statement. Many people are carried away by ideas that appear to them as convincing. It does not appear to be so in Professor Phelps' case. But as a matter of satisfaction, I wish to state that the application of this bleach as an experiment sometimes produces unexpected results. During the past week we were driven to the use of bleach for the preservation of our bacteria beds. Our beds were filled with a sludge impermeable to liquids for a depth of perhaps 2 feet. A quantity of bleach, of which I cannot now recall the figures, was put in, and a repetition of the process two or three times was successful in that it restored the beds to their original condition, and while I am not yet able to say whether it lowered the bacterial efficiency, there is no doubt but that on a large sized plant an application of this kind would save several thousands of dollars, and by the knowledge of the efficacy of such application many units can be maintained in service that would otherwise have to be built as an extra precaution.

Henry Leffmann.—The principles applicable to the use of aluminum compounds in food cannot be applied to the use of these compounds in the purification of water, because the aluminum, in most cases, remains in some form in the food; but, in the proper operation of water purification, none is found in the effluent. The practical difficulty in reference to all systems of purification with coagulants is in regulating the supply of the coagulant. This is generally attempted by use of automatic apparatus, but is by no means always successful. I presented some time ago to the Philadelphia Section of the American Chemical Society a short paper, giving data in regard to the operation of an alum-filter plant in one of the large hospitals in this city, showing, by the tests of the effluent in comparison with the applied water, the great irregularity of the alum-feed.

Aluminum sulphate is the coagulant generally employed, and it must not be overlooked that this, by increasing the sulphates in the water, increases the tendency to form a hard scale in boilers.

P. A. Maignen.—As a matter of history I think the name of L'Hermitte should be mentioned. He was probably, after Webster, the first to use hypochlorite in France.

I would like to ask Professor Phelps if he has any information on the taste of the water after it has been treated with bleach and passed through a sand filter. Whether the chlorin does not remain hugging the grains of the filtering materials and afterward give a bad taste to the water?

I am very glad that the subject of the chemical purification of water and sewage has been presented to this Club. I do not know if anybody has anticipated me in demonstrating that the chemical purification of water brings about *ipse facto* its sterilization. This was done in the year 1890.

The facts that have been mentioned to-night by the Professor and by the last speaker must put a fly in our ear about the use of bleaching water. If this [illegible] filtration and [illegible] filter whatsoever were to be [illegible] [illegible] more than that which is necessary, namely the [illegible] [illegible] accessories.

[illegible] ourselves to alum or bleach, you have the [illegible] [illegible] chosen. But the chemical to the [illegible] [illegible] treated. Lime, for instance, has been [illegible] long time, and it is still used [illegible] [illegible] One of the objections urged against the [illegible] makes a great deal of sludge. But [illegible] make a good fertilizer.

[illegible] opposing the use of bleach as a disinfec[illegible] [illegible] mixed with a large volume of water [illegible] to be appreciable. But I ca[illegible] [illegible] small quantity of the ch[illegible] [illegible] must ultimately leave [illegible] [illegible] the filtered water long after the [illegible] [illegible]

[illegible] chemical engineers. Do not [illegible] [illegible] chemicals. Select the chemical [illegible] [illegible] entering upon the consideratio[illegible] [illegible] it is done. Last [illegible] [illegible] first, you will never [illegible]

[illegible] having brought the ma[illegible] [illegible] necessary for water or sewage [illegible] [illegible] not with an apology. [illegible] said].

[illegible] question about the odor I may [illegible] [illegible] with. If we get the [illegible] [illegible] much organic matter, we through the bacteria beds was more effective than applying it to the effluent finally.

Mr. Phelps.—We have not repeated those experiments. The speaker was correct in quoting Dr. Dunbar. I could never see any reason for doing that. I think the work recently done in Germany was done that way because they had settling tanks in which the sewage was settled before filtration, and they did not have tanks for treatment afterward. We have never followed any such process, because our present system saves about half the bleach.

DISINFECTION OF SEWAGE AND SEWAGE EFFLUENTS.

By EARLE B. PHELPS, *Consulting Sanitary Expert, New York.*

In former days the purification of sewage was commonly understood to mean the removal and final oxidation of practically all the contaminating matter present, including the germ life. The old slow sand-filter was relied upon to accomplish this end, and, although, in the majority of cases, its efficiency is not at all times of the degree indicated, yet effluents can be produced under favorable conditions which approximate drinking water standards. However desirable such results may be, the large amount of land required, about an acre for every thousand inhabitants, makes the price almost prohibitively excessive in the region of large cities. Therefore, the tendency of the times has been toward intensifying the natural process of purification to the end that more sewage may be treated upon a given area. Progress in this direction has been rapid and satisfactory, so that with a modern trickling filter the wastes of 20,000 persons can be adequately disposed of upon an acre of filter surface.

With the increased rate of treatment, however, there has come a consequent deterioration in quality. The removal of bacteria, in particular, has ceased to be one of the chief factors in sewage purification. To what extent pathogenic bacteria are removed by filters of coarse stone is a somewhat debated point at the present time, but it is the writer's belief, based upon many years of experimental study and the perusal of the available evidence, that the removal of pathogenic bacteria by modern processes of sewage disposal is at least not more rapid nor more efficient than that which is observed naturally in a polluted stream. In other words, the same natural processes are at work, and the conditions found in the purifying mechanisms have no especial detrimental effect upon the bacteria in question. This at least is the result of investigations upon the fate of non-pathogenic bacteria of certain specified types which have been studied most exhaustively. Reference is had particularly to the bacillus coli. It has been shown repeatedly that this organism is not destroyed in modern sewage disposal plants to an extent which would have any sanitary significance. It has further been shown under controllable experimental conditions that the resistance of this organism to unfavorable surroundings, to heat, to cold, to chemical poisons, and to simple storage in water, is not much greater, if any, than that of the typhoid bacillus. Therefore, in the absence of any direct evidence to the contrary, it is not only just, but quite necessary, to assume that the fate of the bacillus coli in the various processes of sewage purification is indicative of the fate of its more undesirable relative, the typhoid germ. In summing up the evidence in this matter as presented by English experience, Houston concluded that the biological processes at work in the filters are not strongly inimical, if hostile at all, to the vitality of pathogenic germs.

Granting, then, that these sewage filters present no material barrier against the passage of bacteria from the sewage to the stream, we are confronted by a still more perplexing and unsettled question, namely, the degree of purification which may reasonably and economically be demanded. Sewage purification in the complete sense previously described leaves little to be desired as far as results go; but partial purifications of one kind or another are possible also, and in many cases may satisfy the local requirements. In brief, we can remove suspended solids, which cause offensive deposits in streams unless the flow be always rapid; we can oxidize organic matter which will otherwise produce anærobic or putrescible conditions in a stream unless also the final dilution be sufficiently great; or we can destroy pathogenic germs which might otherwise endanger water supplies or shellfish beds. Finally, we can combine any two or all three of these partial methods.

The adoption of a purification process fitted to the local requirements and going no further than these requirements demand, results in a two-fold good. Communities installing the works are saved unnecessary expense and more communities are finding it possible to purify their sewage, owing to the simplified processes now employed. An example has recently come to the writer's notice. A public institution secured an appropriation of $18,000 for sewage disposal works. Plans and bids were called for and the lowest bids received called for a total expenditure of $22,000 for septic tanks, special pumping apparatus and sand filters. This amount of money was not available, the appropriation lapsed and the work was dropped for a year. A special study of the local requirements showed that by no possibility could any physical nuisance occur below the outfall. The discharge was into tidal waters, the volume of water was great compared with the volume of sewage, and the flow was sufficiently rapid at all times to prevent sedimentation. Extensive oyster beds, however, would be affected by the discharge of crude sewage at this point; furthermore, any large, floating particles would be unsightly. A system involving screening, partial clarification and complete disinfection has been designed for this institution. This system meets the local requirements far better than the first plan proposed, since special care is taken to prevent the discharge of bacteria prejudicial to the oyster beds. The total cost, including the capitalization of the extra operating expenses of the disinfecting process, will not exceed $5,000.

This possibility of adjusting the character of the purification works to its requirements, not only resulted in the saving of public funds, but, what is of vastly more importance, made it possible to put in disposal works which might otherwise never have been installed.

This question of the desirability of disinfecting sewage and effluents has been gone into at some length because, strange as it may appear, we are better agreed at present on the methods of disinfection than we are upon its proper role in sewage purification work. The ever-growing necessity for some kind of sewage treatment, particularly in our larger cities, has led to the development of less and less perfect processes of treatment and the question of sewage disposal has curiously become less and less a matter of sanitation. The prevention of physical nuisances in our streams is now held to be all that is necessary or at least all that is feasible. With the definite knowledge of new processes which make it possible at a reasonable cost to provide bacterial as well as organic and physical purification, the question is bound to arise: "To what extent shall we retrace our steps and again regard bacterial removal as one of the factors of the problem?" The problem is further complicated, as it always has been, by the fact that, while the purification of water directly benefits those who pay for it, sewage purification affects directly only those communities situated further down on the stream. It is, therefore, fortunate that all these matters are being placed more and more in the hands of central state bodies, boards or commissioners of health, who, looking upon the questions involved from the broad viewpoint of public policy, are best enabled to decide to what extent the disposal of sewage shall be carried out. This decision must be rendered upon the broadest of sanitary and economic considerations, and the self-interest of the individual communities must not be allowed to interfere with the general policies laid down by these boards for the public good. More and more, therefore, as the powers and activity of such boards increase throughout the various states, is the opinion growing that our drinking-water streams should be protected, not only from gross physical nuisances, but from serious bacterial infections. It often happens that while typhoid fever is raging in one community, the next community downstream has between its drinking water and the necessarily infected waters of the river, only a poor water filter, oftentimes broken down or greatly overworked. The margin of safety here is too small. It is manifestly unjust to throw upon any water filter the burden of purifying a stream which is being seriously and wilfully polluted and infected by others. This is the position which is being taken by the more advanced of our States, as shown by legislative enactments. It is the position universal among the best sanitarians of the day, and, finally, it is the position dictated by ordinary common sense and by an ordinary spirit of engineering caution. Therefore, it does not seem that one will be charged with undue enthusiasm who holds that, since it is now possible and perfectly feasible to prevent the discharge of pathogenic germs through the sewers of cities into drinking-water supplies of other communities or upon important shell-fish areas, that such steps should be taken and will in the very near future be considered essential.

Let us consider now the methods by which disinfection may be brought about and the all-important matter of costs. Among the agents of disinfection, chemical and otherwise, which have from time to time been proposed, and many of which have been used in sewage work, the following may be mentioned: Heat, lime, acids, ozone, the various compounds of chlorine, including chlorine gas, hypochlorites, and electrolytic products, the salts of copper, manganates, permanganates, and various organic substances. In an earlier paper the writer has considered the historical development of sewage disinfection and has gone with some detail into the possibilities and the costs of the variout agents mentioned. It will be sufficient for present purposes to state that all of these agents, save the chlorine compounds and the salts of copper, are prohibitively expensive, and that of the latter two, chlorine in the form of hypochlorites appears to be by far the most economical and satisfactory disinfecting agent. Early experiments with hypochlorites in both England and Germany indicated that very satisfactory results could be obtained on a practical scale. The cost, however, of these processes were still too high for ordinary routine use as compared with the costs of other sewage disposal processes. Investigations made later in this country by the writer and others indicated that the high cost of the German results, in particular, was due to the excessively high standards of bacterial removal demanded. For example, in most of the experiments referred to it was thought to disinfect the sewage to such an extent that the bacillus coli would not be found in one litre of the disinfected water. Since this organism occurs in ordinary sewage in numbers ranging anywhere from 10,000 to 1,000,000 per cubic centimeter it is quite evident that the degree of purification called for in this case is far in advance of any practical requirements. Our own investigations show that it was comparatively easy to secure a reduction of total bacteria and of the bacillus coli amounting to from 95 per cent to 99 per cent, and that beyond this point excessive amounts of disinfectant were necessary. This phenomenon of the resistent minority, as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals or other means. It is, therefore, decidedly more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To put the case concretely, it might be found that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money; 98 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first, or even the second, proposition might develop into a feasible plan, while the last might be prohibitively expensive. From the practical engineering point of view, therefore, it is plainly our duty to achieve 96 to 98 per cent reduction at reasonable working costs rather than to secure the ideal at prohibitive costs.

On this principle, therefore, it was determined to learn to what extent sewage filter effluents, and even crude sewage itself, could be purified at costs which were commensurate with the results and with the costs of other purification processes. For this purpose experiments were carried on at the sewage experiment station of the Massachusetts Institute of Technology for a period of over two years. Simultaneously with these investigations work was also under way on a practical scale at Red Bank, N. J., where 250,000 gallons per day of septic effluent was treated. Also, through co-operation with the Sewerage Commission of the city of Baltimore, experiments extending over about one year were made at the experimental plant there. At Baltimore the effluent treated was from a septic tank-trickling filter system. It will not be necessary to go into the details of these various investigations, which have already been published in full by the United States Geological Survey, through whose financial aid they were made possible. In brief, it was found that the satisfactory disinfection of a trickling filter effluent which has been purified to a condition of non-putrescibility can be accomplished by the application of ordinary commercial bleaching powder in the proportion of three parts per million of available chlorine or approximately 75 pounds of bleaching powder per 1,000,000 gallons of effluent. The removal of bacteria possible in this way will average over 95 per cent, making a combined bacterial efficiency for the filter and the disinfection of between 98 and 99 per cent. The cost of such a process will range from $1 to $1.50 per 1,000,000 gallons, depending somewhat upon the size of the plant and somewhat upon the transportation charges on the bleaching powder. Effluents of higher degrees of purity can be disinfected at still lower costs. Five parts per million of available chlorine, or 125 pounds of bleaching powder per 1,000,000 gallons probably represents the maximum amount which would ever be required for the treatment of effluents of a poorer quality. The disinfection of crude sewage to the same final condition as that mentioned above, namely, the removal of over 98 per cent of its total bacteria, may be accomplished by the application of from five to ten parts per million of available chlorine, or from 125 to 250 pounds per 1,000,000 gallons of bleaching powder, the amount depending upon the character of the sewage. The cost will range correspondingly from $1.50 to $3.50 per 1,000,000 gallons.

The disinfection of septic sewage required the application of from ten to fifteen parts per million of available chlorine, or of from 250 to 375 pounds of bleaching powder per 1,000,000 gallons. If no further purification is required than that given by the septic action and the disinfection, it will probably be found advantageous to reverse the processes, disinfecting the crude sewage before it enters the septic tank. The resulting development of ordinary bacteria within the tank is of no sanitary significance, and it is doubtless of some advantage in the subsequent purification of the organic matter in the stream to discharge an effluent rich in bacteria which assist in that purification. The removal of the bacillus coli in all of the above cases is usually somewhat more complete than that of the total bacteria cited.

Under the conditions of a laboratory experiment, the results of hypochlorite disinfection on both the colon and the typhoid bacilli, carried out under exactly the same conditions, were identical. It seems reasonable, therefore, to assume that the viability of the typhoid germ under working conditions in practical sewage disinfection is at least no greater than that of the colon bacillus, and, therefore, no greater than that of the sewage bacteria as a whole. Consequently, the disinfection results obtained with the total bacteria may, in the case of chlorine disinfection at least be referred directly to the typhoid bacillus with assurances of reasonable accuracy and of some margin of safety.

In the investigations made, the subject of electrolytic processes of treatment received considerable attention. Many such processes have been developed, and a few have actually been installed. The claims of some of them are so ridiculous that the process disbars itself from scientific consideration. There seems to be something about such terms as "electrolytic" which appeals strongly to the layman, and this weakness on the part of local boards of public works has been played upon in many instances for the purpose of marketing certain patented processes of very dubious merit. At the same time there are electrolytic processes for the manufacture of chlorine which are undoubtedly successful, and, in fact, most of the bleaching powder which we use in this work is made by an electrolytic process at Niagara Falls. It happens, however, that chlorine is practically a by-product of the much more important alkali hat its price is consequently fixed at almost the cost of materials and freight. Granting to such a process free power and theoretical efficiencies, the cost of manufacture on a scale small enough for an ordinary sewage disposal plant would still be above the market price of bleaching powder. Therefore, one is not mistaken in stating that under present market conditions chlorine can be purchased much cheaper than it can be made even under the most favorable circumstances.

In conclusion, the following table of the total costs of operation, including interest on installation, is given. It is based upon the plant having the capacity of 5,000,000 gallons per day, the costs being per 1,000,000 gallons. In general, plants of a larger capacity could be run somewhat more economically, while on smaller plants the labor items would probably mount up somewhat faster. The costs, as will be noted, all refer to the amount of available chlorine in parts per million found necessary. In this way the table can be applied to any situation after it has been determined by experiment how much available chlorine will be required to produce the desired degree of disinfection. In a rough way, the figures already given, namely, from two to five parts for filter effluents of varying quality; from five to ten parts for sewages, and from ten to fifteen or more parts for septic sewages, may be used. A special column is given to the matter of storage tanks, since in many locations this item would not be an extra charge, existing tanks being used. As to the application of results obtained in one place to conditions met in another, it may be said that the reactions involved are particularly free from interference on the part of the mineral constituents of sewage, conditions which have not been found in the case of copper. Thus there is reason to believe that the results given here are of practically universal applicability.

TOTAL COST OF OPERATING DISINFECTING PLANT.

Based Upon a Plant Having a Capacity of Five Million Gallons Per Day.

Av. Cl. Parts Per Million	Bleach. Pounds Per Million Gallons (Approx.)	Time of Contact. Hours	COST PER MILLION GALLONS					
			FIXED		OPERATING			
			Storage Tanks	Other Fixed Charges	Bleaching Powder	Labor	Power	Total
1	25	5.0	$0.10	$0.02	$0.30	$0 10	....	$0.52
2	50	2.5	0.05	0.04	0.60	0.10	....	0.79
3	75	1.6	0.04	0.05	0.90	0.10	$0.02	1.11
4	100	1.2	0.03	0.07	1.20	0.10	0.02	1.42
5	125	0.8	0.03	0.08	1.50	0.10	0.03	1.74
10	250	0.5	0.02	0.16	3.00	0.15	0.06	3.39
15	375	0.5	0.02	0.24	4 50	0.20	0.09	5.05

WATER POLLUTION
AND
WATER PURIFICATION
AT
JERSEY CITY, N. J.

PROF. C.-E. A. WINSLOW
NEW YORK, N. Y.

Reprint from Journal of the Western Society of Engineers
Vol. XV, No. 4, August, 1910

WATER-POLLUTION AND WATER-PURIFICATION AT JERSEY CITY, N. J.

C.-E. A. WINSLOW.*

Presented March 16, 1910.

The case of the Mayor and Aldermen of Jersey City, N. J., against Patrick H. Flynn and the Jersey City Water Supply Co., has been debated in the courts for a period of nearly four years, and during this time many questions of considerable interest have been raised in regard to water-pollution and water-purification. As a water-supply case, I think it will perhaps take rank in the history of the subject as second only to the great Chicago-St. Louis case.

The contract originally made between the defendants and the city provided that the works should be "so constructed and maintained by the contractor that the water delivered therefrom shall be pure and wholesome and free from pollution deleterious for drinking and dometic purposes during the time that Jersey City shall take water by the million gallons. If such works and supply are purchased by Jersey City they shall be delivered to said city as a completed operating plant free from pollution, as aforesaid." That was the real crux of the contract which was the subject for debate in the case. The question came before the courts as a result of the expressed desire of the city to purchase the water-works. It was provided in the contract that the city should have the right to purchase these works at a fixed price ($7,595,000), if all the conditions outlined in the contract had been fulfilled; and the main question at issue was whether, first, the system was calculated to deliver pure and wholesome water, and second, if not, what deductions should be made from the contract price to make good the deficiencies of the supply. There were clearly implied provisions in the contract, and in understandings arrived at between the parties, that sewerage systems and sewage-disposal works should be "constructed or arranged for by the contractor to prevent pollution or to carry off pollution existing in the watershed."

The general conditions of the watershed can best be understood from the map (Fig. 1). The supply is derived from the Rockaway River,—one of the three or four large rivers that flow through the eastern part of New Jersey,— and the watershed above the reservoir has an area of about 122 square miles. On the river, near the reservoir, are three towns of some importance and also a number of villages, the rest of the watershed being occupied mainly by wooded land or by grazing and agricultural country. The principal towns on the watershed are Boonton,—right at the point where the river enters the reservoir,—Rockaway, and Dover; and a smaller settlement of particular importance is the little mining village known as Hibernia, on a team which runs into the Rockaway River, near Rockaway. e population of Boonton is about 4,000; of Dover, 6,300, and of ckaway, 1,600; total population on the watershed above Boonon is 169 persons per square mile. The slope of the watershed in the vicinity of the river is quite steep; in fact, in the town of oonton and in parts of the town of Dover the river practically flows rough the bottom of a sort of bowl, densely populated, and with very facility for introducing pollution into the stream. There were public sewers in any of these towns. It was shown, however, evidence introduced in the case, that a number of private sewers discharged from buildings into the stream and that the torm drains through the towns received considerable direct addiions of sewage from privy-vaults and cesspools, which are of rse bound to overflow at times. The village of Hibernia presented, at the time the suit was brought, a particularly interesting problem of this kind, in so far as it was an excellent illustration of the opportunity for polluting the stream by other ways than the direct discharge of sewage from sewers. Mr. Kuichling described conditions here as follows:

---

*Biologist-in-Charge of the Sanitary Research Laboratory of the Massachusetts Institute of Technology.

"The village or settlement of Hibernia is essentially a mining camp. It contains numerous small houses occupied by the miners and there are about 1,200 to 1,500 people there. Of that number, from 1,000 to 1,200 work underground in the mines during the day. While they are under ground their wastes mingle with the mine drainage water which is pumped to the surface and flows into the brook that runs through this little settlement or village. This village is in a narrow valley with steep hillsides. These houses are not of a high class of construction. They have, many of them, privies adjacent to runways for water—what would be called a water course or depression in the ground not containing running water. Some are only running brooks and rivulets. Pig pens and hen coops and stable yards generally, are located so that the drainage flows off readily. The water in the Hibernia brook is discolored and visibly and palpably polluted, both from what surface water there is as well as from the mine drainage. One of the mines delivers water that is as discolored and opaque as almost any city sewage."

These conditions, as to surface drainage, although a little more extreme than those generally occurring in Dover and Boonton, were typical of occasional local conditions in both those towns. They were continued, not only on the main river, but along the numerous tributary brooks, some of which are shown on the plan, but most of which are not shown. All these brooks and runways, whether they carried water in dry weather or not, were for practical purposes a part of the stream; that is, from privy-vaults located near those brooks the pollution could be carried very rapidly, at times of flood, through these natural runways into the river. It was maintained by experts in the case that any privy-vaults and cesspools within 1,000 ft. of the bank of the stream or of the tributaries might constitute a source of pollution if they were not carefully looked after.

Analytical data showed the Rockaway River to be highly polluted all along its course, the pollution varying but being always considerable, and sometimes very considerable. The bacterial count at the entrance to the reservoir ranged from a normal value of a few hundred up to 15 or 20 thousand after rain; indeed, the polluted character of the Rockaway River water was conceded on all sides. With the exception of minor discussions in regard to the extent of the surface-pollution, and the part played by the agricultural land and the towns in causing that pollution, the main point of contest was in regard to the purifying-efficiency of the reservoir, which is a large one, as shown on the map. It is a little over two miles long and a mile wide, and the greatest depth is about 85 or 90 feet. It contains above the lowest gate from which water can be delivered, 7,300,000,000 gallons, or a supply for 146 days on the basis of the actual consumption of 50,000,000 gallons per day. At first sight such a reservoir would seem to offer ample facilities for self-purification. The water, however, entered the reservoir at one end and was taken out at the other side of the same end, as shown in Fig. 2. The direct line of flow was a comparatively short distance (3,900 feet), and the real question was as to the actual course taken by the water and the degree of purification effected. The discussion of the purifying efficiency of this mechanism is to my mind perhaps the most interesting phase of the first branch of this Jersey City case, and the opinion rendered in regard to it by Vice Chancellor Stevens is an admirable piece of sanitary writing. Few sanitary experts could make such a clear and forcible statement of the fundamental principles,—principles involving a considerable range of hydraulic and bacteriological problems. The Chancellor said:

"The theory is, that when these germs escape from their natural habitat in the intestine their environment becomes unfavorable and hence they tend to die off. Professor Sedgwick, of the Boston Institute of Technology, thus states the matter: 'Once they begin to travel through soil-pipes and sewers, their food becomes scarcer and less available, and when finally they mingle with the waters of the lake, which are relatively pure and destitute of organic matters, their pabulum must be distinctly scanty. At the same time, in sewage and in the lake, they are subject to the influence of gravity which tends to draw them down into the deeper, quieter layers and finally into the mud at the bottom, while predatory infusoria running through the water may devour

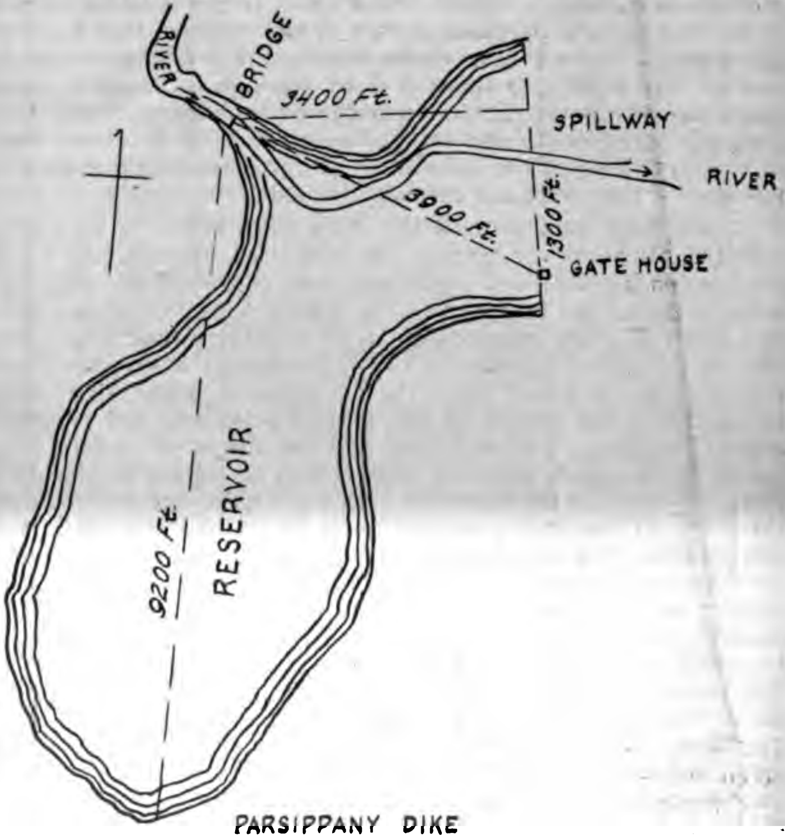
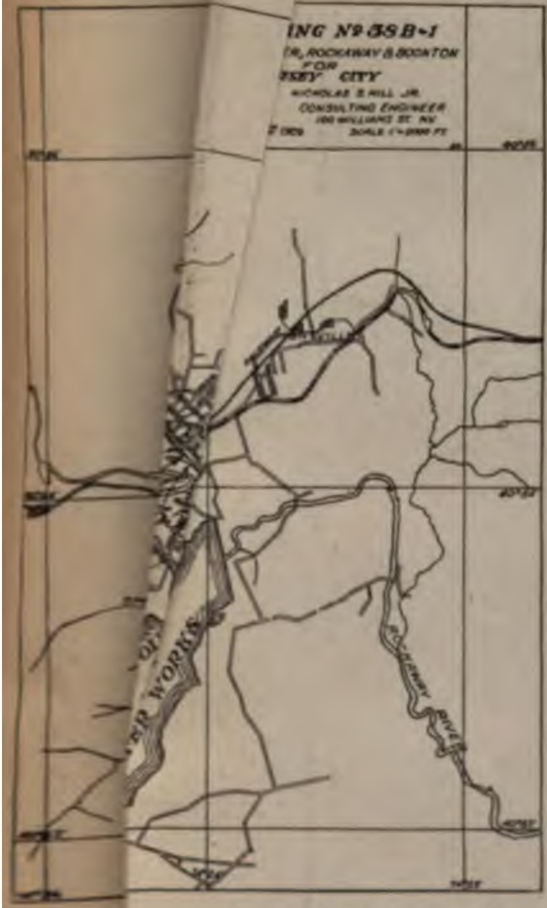


Fig. 2.—Reservoir for Jersey City Water Works.



Courtesy of Nicholas S. Hill, Jr.

the city.

on
tion
here
nger
lent
ase.
be a
still
runi-
ticle
dis-

rage
rms
its
ndi-
own
ying
perts
ces-
e of
was
lden
voir.

cur-
long
the
way.
the
d in
orth-
the
rent.
cur-
the
east
the
shet.
ame
ng's
ents
ward

me

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX AND
TILDEN FOUNDATIONS.

> them altogether. Lastly, if they tend to float or linger on the surface, they may there suffer from the germicidal action of the rays of light and perish.' In addition to what is here stated, several of the witnesses are of opinion that the longer they remain out of the intestine the weaker and less virulent they become, and therefore the less likely to cause disease.
>
> "Now it is on this theory that still water is seen to be a better purifier than running water, but in order that still water may, so to speak, do its work, it must have time. A running mountain-stream may carry the germ and be the vehicle of disease 50 miles below the point at which it was discharged into the water."

Then the Chancellor discusses the actual effect of storage in the reservoir. It is conceded by everybody that if the germs remained in the reservoir for the time which is represented by its full storage capacity, the water would probably be in safe condition, but it was shown that when the reservoir was drawn down and when there was a heavy rain on the watershed, the purifying capacity was much less than that calculated. Some of the experts attempted to maintain the position that the water would necessarily pursue a roundabout course, following down one side of the reservoir to the further end and then back again. It was pretty well settled by the floats, however, that in times of sudden rain, water found its way quickly across the end of the reservoir. In this connection, the Chancellor says:

> "This much would seem to be certain: That the current, such as it is, on the principle that the water goes along the line of least resistance, necessarily tends to flow from the mouth of the river towards the gate-house and spillway. If more water is flowing over the spillway than through the gate-house, then the current would be more pronounced in that direction. If the wind is blowing hard from the northwest, this tendency would be augmented. The larger the volume of water flowing in the river the stronger the current. It nowhere appears in the testimony how far down these currents would extend, so far as they are set in motion by the passage of the water toward the spillway. It is at least probable that the friction of the upper currents upon the lower, created either by a considerable wind or by a freshet, would tend to set the lower currents in motion in the same direction, in accordance with the result of Mr. Kuichling's observations in Lake Michigan, and that these currents would be directed toward the gate-house rather than toward the Parsippany dam.
>
> "There is a fact in this connection which seems to me

to be very strong indeed. I called attention to its significance on the argument, and counsel for the water company could not, so far as I could see, explain it away. In the freshet of 1880 and during 108 consecutive hours, or nearly four and a half days, there was discharged at Boonton 9,885 million gallons. The reservoir contains, above the lowest effluent pipe, 7,300 million gallons. What would have become of the water in the reservoir had it then been full? It is absurd to suppose that this immense volume of water would have flowed over the top of the water already there and left it undisturbed. It would undoubtedly have mingled with it and very largely displaced it. There can be no question that in two or three days some of the inflowing water would have reached Jersey City. It will, no doubt, be said that this was an exceptional flow, but the fact is that a very similar freshet occurred only a year or two before.

"I will take, however, what was admittedly a normal year, in fact, a year of very moderate and very even flow. The flow of 1906 is illustrated by Mr. Cook on a diagram. It appears therefrom that on March 4th and 5th it was about 900 million gallons per day; on March 6th, 600 millions, and on March 7th, 400 millions. In other words, nearly 2,800 millions of gallons flowed into the reservoir during those four days. This was considerably more than one-third the contents of the reservoir above the lowest point of discharge. Now considering with what velocity the freshet must have entered the stream and how the contour of the bottom must [illegible] its currents, how the friction of the [illegible] acted upon the lower, is it con[illegible] considerable portion of the river water would [illegible] way to the gate-house within a very few [illegible] freshet occurred in the early part of March. If [illegible] then the water would have contained [illegible] which had accumulated on the surface [illegible] weather."

[illegible] conditions which have been found to be most [illegible] surface waters, conditions of low storage [illegible] passing quickly across the reservoir —[illegible] occurred at Plymouth, Pennsylvania, in 1885 [illegible] more recently—there was a strong probab[illegible] of the reservoir would break down [illegible] that such was the case. The total number [illegible] fairly low in water collected at the [illegible] but the results are notably variable. According [illegible] examinations made for the Water Company [illegible] during a period of three years, 5,400 bacteria were found on one occasion; three other samples showed counts over 1,000, and eight others gave numbers between 500 and 1,000. At Jersey City, after passing through the 22-mile conduit, the bacterial condition of the water is of course better, but the same sort of irregularities are manifest. Mr. G. C. Whipple (for the city) found numbers varying between 120 and 2,500 in 1904 and between 210 and 2,400 in 1905; Dr. McLaughlin's results were not very different; and all along, as the Chancellor showed in his review of the evidence, high counts and the presence of colon bacilli were associated with rains on the watershed and sudden rise of water in the reservoir. Melting snow produced high water on December 22, 1906, and on December 26, 1906, I found 2,200 bacteria per cubic centimeter at Jersey City; in the afternoon of the same day, and on the 27th, the numbers fell to normal values of 150 and 200. The reservoir rose again rapidly on March 13th and 14th, 1907. On March 19th I found counts between 600 and 1,200 at Jersey City, and *B. coli* present in one-tenth of a cubic centimeter.

In order to meet these facts the experts of the company fell back on average analyses, and on this basis made out a fairly good case. Taking all samples throughout the year, colon bacilli were present only 7% or 8% of the time, and the average efficiency of storage compared not unfavorably with that of many water filters. The experts for the city maintained, however, that conclusions based on the proportion of samples showing *B. coli* rested on the assumption of unchanging conditions, and did not apply to a varying purifying mechanism like a reservoir. In the Chancellor's words:

> "If 50 samples were taken from the same place on the same day and it were found that *B. coli* were not present in one cubic centimeter in more than 50% of the samples, then the water would be considered good; but if one sample were taken on one day in each week of the year and it were found that on 45 days *B. coli* were not present and on 7 days they were, all that that would indicate would be that on 45 days the water was good and on 7 days it was either bad or, at least, open to suspicion. We certainly would not be justified in concluding that it was unobjectionable during 7 weeks (if a day is to stand for a week), only because it was good for 45 weeks; if, in point of fact, it were found that for those 7 weeks it was bad."

From this point of view, and judging the character of the water by the colon tests made by the company's own experts, the Chancellor concluded that:

> "The water was of doubtful quality in 1904, 7% of the time; in 1905, 5% of the time, and 1906, 8%. This, in days, would

> be, in 1904, 25½ days, in 1905, 18 days, and in 1906, 29 days, or, if we include Prof. Winslow's analysis 31 days."

This careful study of the efficiency of a reservoir in self-purification led, as I have stated, to the conclusion that generally the reservoir worked excellently. At times, if the conditions of water in the reservoir, the stream-flow, wind, etc., were right, the purifying mechanism (generally efficient) broke down and large numbers of bacteria were carried across the intake. It was even claimed by the experts on the city side that on one occasion there was a slight increase in typhoid fever in Jersey City following one of these lapses. The evidence was not conclusive on that point, and the general death-rate from typhoid fever was exceedingly low; in fact, Jersey City has one of the lowest death-rates from typhoid fever in this country. Nevertheless, the evidence was sufficiently clear to convince the Chancellor that there was danger on those few days in the year when conditions were just right to make the reservoir an imperfect purifying-mechanism. Of course, the question whether typhoid fever did or did not follow those breaks had no important bearing on the practical proposition. It might easily be that for a number of years there would not be typhoid bacilli in the Rockaway River at just the right time to be carried across. Nevertheless, if the pollution existed, there was always the chance that at some time the specific infection would be present. As the Chancellor stated the case:

> "I am, on the whole, obliged to conclude that all the evidence favors the theory that water, under certain combinations of circumstances occurring perhaps on an average two or three times a year, will pass from the mouth of the river to the Jersey City reservoirs in two or three days. Every fact is favorable to this view and no fact, so far as I can discover, is opposed to it."

The Court therefore reached the opinion that "Patrick H. Flynn and the Jersey City Water Supply Company have not complied with those provisions of the said contract which stipulated that the supply of water delivered to Jersey City shall at all times be free from pollution, it appearing that the works, as a mechanism for the purification of the supply, are not at all times adequate and reliable."

It was therefore decreed that "There shall also be deducted from the contract price the cost of establishing intercepting-sewers and drains and sewage-disposal works, capable of substantially preventing the contamination of the Rockaway River above the Boonton Reservoir from the sewage of the City of Dover, the City of Boonton, and the Village of Hibernia, which cost shall be hereafter determined by the Court."

It was also provided that the company might "in lieu of and as a substitute for all or any of the sewers and sewage-disposal works . . . present other plans or devices for maintaining the purity of the water delivered by the company to the city throughout the year." Evidence in regard to these plans or devices and their cost, and in regard to the cost of the sewers and sewage-disposal works, was to be presented before a special Master,—the Honorable William J. Magie. This constitutes the second branch of the case, on which the evidence is now all in, but on which a decision has not yet been rendered. The experts for the city have proposed sewage-disposal works of several types. The sewerage plan, which was at last practically agreed upon by experts for both sides, was for a trunk-sewer running down the Rockaway River from Dover to a purification-plant below the Boonton dam. I believe the plan of the company's experts provided for a trunk-sewer on one side and the city's experts on the other, but there was very little difference in either the designs or the estimates. The collecting systems differed in extent, but the revised plans of Mr. Nicholas S. Hill, the principal engineering witness for the city, were only $544,540, against estimates of $376,005 by Mr. Rudolph Hering, and $420,595 by Mr. G. W. Fuller, for the company. For Hibernia, where there is no water-supply available, Mr. Hill proposed a pail-system of collecting and disposing of excreta at an estimated cost of $23,475. Furthermore, the city maintained that the capitalized cost of operation and due allowance for depreciation should also be included, bringing the total deduction up to $872,744.

The company's alternative plan, which was, of course, much cheaper than any sewerage system, was a chlorine-disinfecting plant for treating the water as it was taken out of the reservoir. This plant—which was made possible, I think, by the experiments carried out at "Bubbly Creek" at the Chicago Stock Yards—is described in the *Engineering News* for June 24, 1909. As all its details may not be familiar to the society, I will refer briefly to some of them.

The plant as used at Boonton contemplated no filtration of the water but simply treatment either with chloride of lime, or with hypochlorite of sodium produced by the electrolytic treatment of salt. In either case the action is a simple disinfection.

I should not, perhaps, say that the action is simple, however, because a great many pages of testimony were wasted on the discussion as to whether it was the chlorine that killed the bacteria or whether the chlorine liberated oxygen that killed the bacteria. At any rate, there is no doubt that when hypochlorites are added to water or sewage containing bacteria, a large proportion of the bacteria are killed. The plant involved tanks in which the bleaching powder was dissolved, orifice tanks to which the solution was pumped and from which it was wasted over a waste-weir continually, and a grid through which the solution of bleaching-powder was discharged into the stream of water coming from the reservoir at a number of points, insuring a fairly perfect mixture. The amount of bleaching-powder added at first was 36 pounds per million gallons, equivalent to 1.4 parts per million of available chlorine, and about 4.2 parts per million of bleaching-powder. Gradually the amount was cut down to 5 pounds per million gallons, corresponding to 0.2 of a part per million of available chlorine, or 0.6 of a part per million of bleaching-powder,—a very minute dose for this large volume of water. The result was the production of an effluent in general very low in bacteria. According to the experts for the water company, bacterial numbers ranging from 30 t 500 were cut down to an average of 15 per cubic centimeter, during a period of a little less than three months, the colon bacillus was found by the company's experts only once out of 455 tests (*Engineering News*, LXI, 699). Clearly the bleaching-powder exerted a strong bactericidal action. The city contended, however, that the plant did not fulfill the contract and did not supply a pure and wholesome water throughout the year. This contention, which, of course, is not yet an accepted one, being still before the Chancellor,* was based on several considerations, and in reviewing them I can only be held responsible for my own opinions, as I have not studied all the other experts' testimony in the case on either side.

In the first place, the city maintained that the disinfection-plant at the Boonton dam could not properly be held to constitute a process, alternative to the construction of sewers and sewage-disposal works on the Rockaway watershed. Sewage-disposal and water-purification are not interchangeable processes; both are essential according to modern standards. It was Mr. Hering, I think, who coined the aphorism, "Nothing put into a stream without purification, nothing taken out of a stream without purification." Sewage-purification should keep out the grosser pollution, but water-purification is still required at the other end to remove the incidental pollution that must get into any surface-water. To quote from Mr. Hill:

> "It is not sufficient to boil sewage or treat it chemically and then drink it. Under the special condition of flood following low water and accompanied by westerly wind, with

---

*Hon. W. J. Magie, the Master in the case, has recently rendered an opinion, supporting the contention of the water company in regard to the character of the disinfected water and the propriety of substituting a disinfecting plant for sewage disposal works. • The final decision of the case of course rests with the Chancellor.

which the present case deals, the water at the dam is not a proper raw water for safe treatment. Jersey City, in order to have a safe supply, must remove gross sewage-pollution and then purify the water at the dam. It is therefore manifestly unjust that the water company should evade the more costly fraction of the necessary burden which it contracted to bear."

Besides this primary contention, that a disinfecting plant could not properly be accepted as "in lieu" of sewage-purification plants, the experts for the city maintained that chlorine disinfection, as practiced at Boonton, did not yield a water "pure and wholesome and free from pollution deleterious for drinking and domestic purposes." For the most part, the water delivered at Jersey City was of excellent quality as judged by the ordinary bacterial tests, but there were still irregularities, which coincided as before with periods of heavy rain on the watershed. For example, near the end of October, 1909, there were severe rains, and on four days following October 26th, several samples of water at Jersey City showed colon bacilli present in 6 or 7 out of 10 one-cubic-centimenter samples. These were only occasional samples, it is true, for others collected on the same days failed to show intestinal organisms; but there were similar findings of intestinal bacteria on January 28, and on March 4, 1909, as shown by the analyses reported by the experts for the city.

OnMarch 4th, the following results were obtained by Dr. Charles E. North:

BACTERIOLOGICAL EXAMINATION OF WATER AT JERSEY CITY, MARCH, 4, 1909.

Sample.	Bacteria per c. c.			*B. coli.*	
	20°	37°	Acid Formers.	Lactose bile.	1 C. C.
				+	—
1	3600	367	200	7	3
2	620	700	220	0	0
3	1800	520	210	4	6

The experts for the Company also noted the pollution of the water on this occasion. Similar excessive numbers of intestinal bacteria were testified to in August, September, and October, 1909, by Doctors Jackson and North, experts for the city. It seemed to me and to others that these high numbers of bacteria were due to the fact that the sudden increase in organic matter sweeping across the reservoir at times of rain was too much for the normal dose of bleaching-powder, and this possibility apparently constitutes one fundamental defect of the process. When a burden of extra organic matter is put on a slow sand-filter, it works with a higher percentage of efficiency than before, but

a waxy envelope or of waxy substance, like the tubercle bacillus, and spores like anthrax and *B. sporogenes,* which are still more resistant to the action of the disinfectant. There is danger, therefore, that when the colon bacilli are removed these other types may remain. The amount of chlorine used in disinfecting water would almost certainly not affect spore-formers like the anthrax bacillus, which has several times, in recent years, been transmitted in water to cattle, and might just as well be transmitted to man; it seems probable, too, that it would not destroy the tubercle bacillus which gets into water from the sewage of man and from the excreta of cattle, and which recent investigations have shown to be, to an appreciable extent, a water-born disease.

In the third place, the possibility has appeared in the last few years that water-supply may cause disease in other ways than by transmission of living specific germs. The fact that typhoid fever is by no means the only disease caused by polluted water was shown first in this country by Mr. Hiram Mills, of the Massachusetts State Board of Health, and was enunciated in clear and definite form at the Engineering Congress in 1904 by Mr. Allen Hazen, having since become known as the Hazen theorem. The Hazen theorem is that for every life saved from typhoid fever by purification of water, two or three lives are saved from other causes. This fact has been established, I think. When pure water is introduced, there is a fall in the general death rate much larger than can be accounted for by the fall in the typhoid death-rate. Professor Sedgwick has called attention to the fact that among the specific diseases affected in this way are tuberculosis, pneumonia, bronchitis, and infant mortality. Just how these diseases are affected we do not know. Whether the germ is carried in the water—as seems probable in the cases of tuberculosis or whether there are other substances in the water that have a lowering effect on the vital resistance—which seems perhaps a more probable assumption in the cases of pneumonia and bronchitis—we do not know. But the fact that other diseases than typhoid fever are caused by polluted water makes uncertain the value of a process which simply kills certain kinds of bacteria and does not remove other deleterious substances.

This case will, I think, take its place as one of the historical law-suits in connection with the subject of water-supply, and in closing I will call attention only to what seem to be the two main results.

First, the case led to a full and thorough discussion of the philosophy of self-purification. Of course, the Chicago-St. Louis case was the first great demonstration of the extent of self-purification of streams, and showed that it is an enormous force; also that it is possible to discharge the sewage of a city like Chicago into the water-supply of a city like St. Louis under the proper conditions of dilution and self-purification, without any increase in death-rate, great enough to be demonstrated to the satisfaction of the Supreme Court. In the Jersey City case the shortcomings of purification by dilution were strikingly brought out, and I think that is a very important point in connection with this whole subject. Self-purification, while it is a very real method of water-purification, is yet an unreliable method; conditions in a reservoir or lake are constantly varying, and a purifying-mechanism of this kind that may be ample and efficient for 350 days of the year may fail on the other 15 days—a lesson of caution in the use of this process of self-purification. It is a valuable process, but unless the self-purification is considerable, unless the storage period exceeds two weeks or more at all times, and under all conditions of weather and flow, then the system is not one which is absolutely reliable, and requires another safeguard.

The second feature of the case succeeded in demonstrating the great value of the process of the bleaching-powder treatment, and it is said that today this process is in use in about one hundred plants in the United States. It was shown conclusively, in connection with ordinary water-bacteria and the colon bacilli,—the principal signs of danger in supplies of fairly good quality to start with—that bleaching-powder would secure excellent purification for almost all the time at a cost so light as to be practically nominal. The estimate made by the experts for the company was perhaps well within the range of probability, but they figured that it would cost them only 14c. a million gallons, which is [illegible] is now used, as you are aware, in many places [illegible] filters,—at Poughkeepsie, N. Y., and [illegible], in connection with slow sand-filters; and at [illegible] Harrisburg, Pa., and a great many other plants [illegible] mechanical filters, where the bleaching-powder process [illegible] added safety to the water [illegible] considerably the cost of operation. With [illegible] enough alum to get rid of the clay and [illegible] a great many bacteria the [illegible] considerably reduced. Chlorine has been used [illegible] Ridgewood, N. J., for purifying well-supplies, [illegible] has been used with great success—as at Minneapolis [illegible]—in treating river-waters. This process marks a great advance in water-works practice, but it is important that [illegible] it should not be misused. The [illegible] having been overcome, the engineers and chemists who have worked with this process are likely to think it will do anything. I do not believe that the bleaching-powder process will work miracles and that it will be possible, by its use, to turn sewage into drinking-water, but I do believe that it adds a third to our two recognized methods of water-purification, storage, and filtration. My own view of the matter is that with the increasing recognition of the importance of pure water, and of the growing opinion that water causes disease in various ways, at least two of these three safeguards ought to be used; that treating a stored water, a lake water, or a reservoir water—any well stored water—by chlorine or by filtation, will funish a satisfactory supply, and that for a river-water supply which has not been stored, both filtration and bleaching-powder will give the best results. Of course, just how far it is necessary to go in these respects will be shown by practical tests carried on in the next few years. At any rate, it is important that this new process should have as a net result the improvement of the character of our water-supplies; it ought to enable cities with poor water-supplies to get fairly good ones, and cities which have fairly good water-supplies to get excellent ones, but it ought not to be made a means for lowering sanitary standards by substituting partially purified supplies for those that are well purified.

Discussion.

Mr. A. Bement, M. W. S. E., chairman: We are fortunate in having had presented to us a matter of such vital interest, and I am not sure but what it should bring to us a lesson here in Chicago. We have been disposed to consider, in the past, that we had a very good water-supply and that it could be used without question, but ideas have changed and I think it would be well to take into account the facts that have been presented, when considering our own situation.

Prof. A. N. Talbot, M. W. S. E.: The presentation of this interesting subject brings to mind to all of us, I think, in a new way the great importance of this method which has been developed within the last few years. It is quite possible that the use of bleaching-powder may some day be of advantage to Chicago in treating its water-supply, making the second of two methods which Professor Winslow has stated should be used, an additional safeguard to the storage obtained in the great lake. It seems to me that the Society is fortunate in having the matter presented, so ably and so completely, by Professor Winslow.

Mr. B. J. Ashley, M. W. S. E.: I am deeply interested in the subject of water-purification. An instance of water-pollution came to my notice this week, which I will mention. In a letter from Rochester, N. Y., information was revealed that several neighbors outside of the sewer district had been advised by the local plumbers and, I think, by an architect, that to dispose of the sewage from their houses they could dig large cesspools about 12 feet square and 12 feet deep, with a dividing-wall of brick, laid up without mortar, running through them; and that by drilling a hole some 30 or 40 feet into the ground below the cesspools they could tap them and run the surplus liquid off into an underground vein of water known to be passing below. I regret to say that one of the men who tried to take advantage of that kind of sewage-disposal was an ex-brigadier general. So far as civic conscience is concerned, such an act is little short of criminal. While no doubt they obtained their supply from the city water-main, yet wherever that underground vein penetrated and carried the underground current, the possibility of its affording water-supply for neighboring wells is very manifest, and how many wells may be taking water from this vein, even at some distance away, is not known. I could not refrain from writing to the Secretary of the State Board of Health of New York, stating the case to him, but I did not inform him where this instance was occurring.

In the matter of pollution of streams by sewage, I recall a former statement by Professor Winslow, and I wish to ask him to what degree of dilution are the recognized requirements? I think I recall his saying that a dilution of thirty to fifty parts of water to one part of sewage, or of effluent, was considered satisfactory and would prevent a nuisance.

I am glad to note that throughout the country there is a decided advance in the matter of sanitary conscience. People are beginning to learn—and the death-rate is lessening because they are learning—as we all know, and one reason is because of the attention that is being paid to water-supplies and to sewage-disposal.

[illegible] The protection of drinking water is somewhat out of my line, but this particular topic was discussed in my presence last summer by Mr. Alvord soon after the experiments were made at Boonton, N. J., and at that time Mr. [illegible] suggested that possibly the hypochlorite process could be used for the drinking-water here in Chicago. Some one made the suggestion that it might be applied at the cribs, and the further suggestion was made that it would be quite practicable to apply the process at the pumping stations. When the pumps are discharging a constant quantity of water—a measured quantity of water—an exact proportionate amount of the disinfectant could be used, and it would be a comparatively simple matter to arrange the mechanism. The suggestion was made that while perhaps the process would be unnecessary at present, if analyses at any time indicated pollution of the water at the cribs it could be put into operation temporarily for use as long as it might be needed.

I infer from Professor Winslow's remarks that he does not approve of converting the sewage of "Bubbly Creek" into drinking-water, but perhaps he would not want to be quoted on that proposition specifically.

Dr. Frederick O. Tonney: Several suggestions have been made this evening which I think are pertinent to the situation in Chicago. The one made by the last speaker occurred to me some time ago and I think it is a valuable suggestion. I think it is quite well established that the city of Chicago has an excellent water-supply, as water-supplies go, but there are some things in connection therewith that are still somewhat unsatisfactory. The cribs supplying the main downtown district, and in fact those supplying most of the districts of the city are showing very good results, as indicated by the analysis in the city laboratory, but according to these analyses there are two stations which will bear watching. One is the Rogers Park pumping-station, the intake of which is located within a short distance from shore. A filtration-plant has been recently installed in that station, but up to the present time the water still shows a rather high colon bacillus content. The typhoid rate in that vicinity has also been higher than in other portions of the city. The other station I had in mind is that supplied by the Sixty-eighth Street or Hyde Park crib. This is the only crib which is located within what may be considered dangerous distance of a sewer outlet. The Seventy-ninth Street sewer is still discharging into the lake within a distance of perhaps two miles, and in addition it is probable that at times the sewage of the Calumet River is carried as far north as the intake. As is to be expected, the bacterial tests show evidence of occasional pollution, although this is of rare occurrence. It seems to me that in these two stations quite satisfactory results might be obtained by the addition of a germicide applied as a temporary measure until the polluting agencies mentioned could be remedied. I think that the hypochlorite treatment offers, as suggested, a valuable remedy in such cases, and it no doubt represents a valuable addition to the accepted methods of water-purification.

Another point which I have in mind, now of interest to the city of Chicago, is bearing upon the germicidal-treatment of water, in connection with the "Bubbly Creek" suit. While, of course, the matter is still in the courts and it is, therefore, hardly proper to draw conclusions from the evidence thus far introduced, yet it occurs to me that this case affords an apt illustration of the danger (a natural tendency as a result of over-enthusiasm) of going too far,—of assuming that the process will do more than the facts warrant. No doubt the hypochlorite-process is valuable for the treatment of somewhat polluted waters,—waters which can still be recommended as proper sources for drinking purposes,—but it seems to me that it is going a step too far to try to convert a fresh sewage directly into a potable water by any process as yet developed on a practical scale. Of course the tter will be fought out in the courts and the best evidence on h sides will be presented. At the time of the decision we ll be in a better position to discuss the points at issue.

The subject presented by Dr. Winslow is a matter of vital rest to us all. Personally my attitude is from the standpoint hygienist and physician, and as I am not an engineer, many the practical phases of the problem are perhaps not as clear ne as they are to some of the members of the society.

Mr. Bement: Concerning our water-supply from Lake higan, on a great many mornings, I have observed water in bath-tub which has come out of the cold-water faucet which so dark that I could not see the bottom of the tub, and some- es it has been black. That condition seems to occur after we e had a north or northeast wind, and I have supposed that the ble was due, in a measure, to the dumping of dredgings in ake.

Mr. Langdon Pearse: There are several points I would like peak on. I was connected with the Jersey City work on the de at the time the suit started and made the sanitary sur- the watershed there under the direction of Mr. George e, so I might say I am familiar with every inch of the connection with the case, although I have not been with the work since 1904. There is not a sewer on the shed. As Prof. Winslow showed, there are several towns the watershed—Dover, with a population of about 6,000; Rockaway, about 1,600, and Boonton, about 3,900.

Hibernia was really the worst place—an iron mine employing about 800 men daily in the workings, and all of their execreted matter was pumped out in the mine drainage into a creek running down into the Rockaway River. At the time, we regarded Hibernia as the place requiring the most immediate attention, but we had not developed any scheme to fix it then. It will probably interest the members here who do not come in contact with such things to explain that, in our sanitary survey, we took the census of every house on the watershed which could in any way drain into the water supply, and listed the provision of sewage. In most cases this meant an inspection of the privy and barnyard. These were all mapped and submitted as part of the evidence. Most of the pollution was scattered. Some of it, of course, came in direct from privy vaults that dumped into the stream and from water closets discharging into it. The latter were mostly concealed, but we found that the water company's inspector had been in collusion with the people he was supposed to stop, and that many things had gone on unknown to the water company, although they were doing their best to prevent pollution.

The question of the pollution of the reservoir at Boonton was interesting, and I am glad to hear what Prof. Winslow had to say on it. We thought at the time, that is, before the float measurements were made, that it was highly probable in time of storm that the pollution from the surface wash as it came down the river might be swept right across the reservoir directly into the city supply. We felt that the water really ought to be filtered, although the turbidity was not very high. At that time disinfection had not been developed for the protection of such a water supply. The question of storage is important, but it would not protect in a case like this.

The question of the cost of treating the water by the use of bleaching powder brings up a question which I would like to ask, "Is the cost of 14 cents computed for the making of the hypochlorites by the electrolytic process with the electric power free, or is it for the use of bleaching powder?" The Boonton reservoir has a massive concrete dam, rock-faced, with an available fall, I think, of over 65 feet. That power usually goes to waste but could be utilized to generate electricity to transform salt into hypochlorite of sodium. If that is being done, the cost at Jersey City would not be comparable to what we would have here, for instance, to treat the Sixty-ninth Street crib, although I suppose the Sanitary District would be glad to sell its power at a cheap rate to make sodium hypochlorite for the sterilization of Chicago's water supply.

In connection with the water-supply of Chicago and the towns on the north shore, Dr. Tonney, Prof. Bartow, and myself have carried on a series of experiments as far north as Waukegan and have studied this question of turbidity which your Vice-President, Mr. Bement, speaks of, and we find it is not so much the distance from shore that is the element involved, but the question of the depth at which waves will affect the bottom. We find beyond forty feet depth that there is not much wave action, although at the time of heavy storms a slight action may be noticed. In thirty feet of water it is more pronounced, and in twenty feet almost every wind stirs up the bottom. This is probably the condition around the Chicago cribs because they are in shallow water, none of them in more than thirty feet, if I remember correctly. There has also been more or less dredge dumping around them in the past and spoil deposited from the water tunnels themselves, which is being stirred up by every wind. In that connection I believe the pollution from the Calumet undoubtedly affects the Sixty-ninth Street cribs at times, and I believe always will do so until the Sanitary Canal from the Calumet to the Sag reverses the flow of the Calumet River.

The question of pollution that Mr. Ashley asked in the case of this Boonton reservoir would not apply on account of the actual lack of sewage facilities on the watershed. It is rather curious that such communities should have grown up for so many years without any sewers, but they did, and still flourish.

In figuring dilution, for instance, as in the case of the Chicago Drainage Canal, which has a dilution much less than the relation of one to fifty, that Mr. Ashley asked about, we stated that there was a dilution of three and three-tenths cubic feet per second for every one thousand inhabitants. If this be figured on a per capita water consumption of two hundred gallons per capita, the dilution is about one to eleven. The statement per capita is more comprehensive than the ratio of dilution in gallons on account of the wide difference in the consumption of water and flow of sewage in different communities. At the Thirty-ninth Street Testing St[illegible] we [illegible]d that the per capita flow varies from two hundre[illegible] hundred gallons per capita daily, with a water cons[illegible] Chicago of about two hundred gallons per capita. A[illegible]s, Ohio, the consumption of water was about one hund[illegible]enty gallons per capita, and in Massachusetts so[illegible] as low as sixty gallons per capita and a few ev[illegible] try to express such figures for sewage work, pa[illegible]on, in cubic feet per second per 1,000 inhabitants. [illegible] the Chicago drainage canal of three and three-te[illegible]per second per one thousand inhabitants gives a re[illegible] a nuisance. It would not be safe to drink it at L[illegible] probably not at Peoria on account of the time lim[illegible] for s[illegible]rification.

Mr. Bement: I think there is no question in the mind of any of us here this evening, or any of the citizens of Chicago who have given thought to the matter, but that it is desirable to have the Sag cut-off to carry away the sewage from the Calumet district. I hope it will not be long until it is begun and that we shall have the water flowing through there as soon as possible.

Mr. Charles B. Burdick, M. W. S. E.: There is no question but that the subject which Professor Winslow has presented is of great importance. It should be noted, and I believe that Professor Winslow has emphasized this point, that hypochlorite is not a panacea. A good water must be not only healthful, but pleasing to sight, taste, and smell, and no water is acceptable for the use of human beings that does not posses these requisites. Hypochlorite will not clean a dirty water, although it will practically kill the germ life therein, and therefore, except in case of emergency, its usefulness is confined to clear waters. There are, however, many situations where its use will make a perfectly acceptable water.

The opinion has been quite well grounded among sanitarians that a surface-water should be filtered before it is used for domestic purposes, and the term *surface-waters* includes many waters—particularly from lakes—that are acceptable in every other respect than their germ content. Such waters as these can be rendered entirely acceptable by a treatment with hypochlorite.

There is a further field for the use of hypochlorite in the treatment of shallow-well waters. There are many cases where wells for municipal supplies have been sunk in such situations that the sanitary character of the water cannot be endorsed. There are other situations where the environment of the shallow wells may have been originally good, but where municipal growth has changed the original conditions. Such situations are no doubt legitimate fields for the use of hypochlorite.

Apparently this disinfectant has a further usefulness in the treatment of a filtered water. Our best filtration-plants at times leave considerable to be desired in the sanitary character of effluents, and hypochlorite has evidently been applied as an adjunct to filtration with excellent success. Used in connection with mechanical-filtration, it seems to permit a reduction in the quantity of coagulants used. There appears to be situations, especially in the case of waters of low turbidity, where hypochlorite can be applied in conjunction with the coagulants, and improved sanitary results secured, with a net decreased cost in the purification process. One of the most striking uses of hypochlorite has been its use as a temporary means of correcting quickly a contaminated water-supply. There is no other germicidal remedy that can be so quickly, easily, and cheaply applied.

The paper has been useful in pointing out some of the objections to the use of hypochlorite. Any process that promises so much should be carefully examined, because frequently misuse gives a process a bad reputation. It is quite possible to so overdose a water as to create a medicinal odor, which is a serious objection. I have heard of a case where about ¼ of a grain per gallon produced a perceptible odor, and there are probably many waters which will not stand anything like the amount of hypochlorite that has been successfully used upon the water of the Boonton reservoir.

I am sure it would add to the paper if Professor Winslow would enlarge somewhat upon the effect of overdosing on the general acceptability of the water, and its effect upon the human system.

CLOSURE.

Professor Winslow: In regard to the cost of treating water by bleaching-powder, mentioned by Mr. Pearse, the cost of 14 cents included the price of bleaching-powder. The free power was used in the plant for mixing and other things. Hypochlorite made from salt is now being used, making the cost still less.

One reason why the towns mentioned have not built sewers is because they are waiting for Jersey City or the water company to do it for them. That is one of the unfortunate results of the whole legal complication.

Mr. Ashley asked about the degree of dilution of sewage which might be given as a recognized requirement. The proportion is one to fifty parts of sewage, but this standard of one in fifty was simply a limit beyond which nuisance would not occur, so that a stream would not become a cesspool; it was not, of course, a question of a potable supply.

Referring to the point raised by Mr. Burdick, I do not think there is evidence that would lead one to believe that the slight amount of chlorine left in the water after treatment under ordinary conditions would be sufficient to have any effect on health. But where the amount is considerably in excess of that necessary to do the work, there may be what is called a chemical or medicinal taste or odor, which is really the odor of the chlorine. That happened, I think, recently at Quincy, Illinois, and is particularly liable to occur when the attempt is made (as it was there) to add chemicals to the water in small quantities with rather crude dosing devices; under such conditions larger amounts get in at one time than at other times. Another thing that sometimes causes an odor is the decomposition of organic matter. When chlorine is first applied it often kills the fungi in the water-pipes and as they die and decay they give an odor to the water.

There were two points I was especially glad to have brought out. One of the speakers intimated that my position would imply disapproval of the "Bubbly Creek" project. That is a point which I have been striving to impress on the lawyer for the Stock Yards company all day. He has been asking me questions about it for four hours and I do not know whether I have conveyed the idea to him or not. I am glad, however, to have conveyed it to this meeting.

The other point was in regard to the application of the bleaching-powder process to the Chicago water-supply. One of the things I had strongly in mind when I came to Chicago, and have had ever since, was the hope of getting some people interested in that proposition. This process should undoubtedly be installed at an early date, for it is exactly the thing to make the Chicago water-supply right, in the places where now it is weak. The cost is very small indeed and there is no reason why water from the Rogers Park or Hyde Park cribs should be delivered to Chicago in a doubtful condition a month longer. Where conditions are very bad, as at Montreal, the process has been put in without question. Of course Chicago's supplies are not of that character—they are not grossly, heavily polluted,—but yet they are at times polluted and this condition ought not to exist.

Reprinted from Proceedings of the Second Meeting of the Illinois Water Supply Association,
Urbana, Illinois.

THE FIELD FOR WATER DISINFECTION FROM A SANITARY STANDPOINT.

BY C. E. A. WINSLOW.*

There can be no doubt that the development of a practical method of water disinfection during the last two years marks an epoch in the art of water purification. No such important step has perhaps been taken since the demonstration of the value of mechanical filtration at Louisville over ten years ago. Mr. George A. Johnson and his associates in the firm of Hering and Fuller, have opened up a new field of engineering practice and have rendered a notable service to the community.

It is curious to see the hope of a process for the disinfection of water realized at last after so many years of fruitless effort. Numerous attempts have been made along this line, with ozone, permanganates, bromine and copper sulphate as the principal chemical agents. Ozone proved efficient from a bacteriological standpoint, but practical difficulties in construction and operation have made its production costly and uncertain. Mechanical improvements are constantly being made, and at any time an economical ozone plant may be designed; but so far this possibility appears not to have been realized. Bromine and the permanganates have never been seriously suggested for the regular treatment of water supplies. Copper sulphate enjoyed a brief vogue a few years ago; but it was soon demonstrated that its efficiency was much less as a bactericide than as an algicide and that its action was easily inhibited by the presence of both organic and inorganic substances.

The possibilities of bleaching powder as a water disinfectant, were, as it seems now, strangely overlooked. Its efficiency in the disinfection of feces had long been known. It was used as an emergency measure to clean the water mains after a typhoid epidemic at Maidstone, England, in 1897. Under somewhat similar conditions it was temporarily applied to the water supply of Lincoln, England, in 1904-5. Sewage disinfection by means of bleaching powder had frequently been carried out in Germany during typhoid and cholera epidemics, and at a few places, as at Brewster, y produced chlorin was regularly used for sewage reatment. For the most part however the amounts of chlorin used for water or sewage treatment were rather large and the process was regarded as an emergency measure, rather than as a routine procedure for water purification.

---

*Biologist in Charge of the Sanitary Research Laboratory of the Massachusetts Institute of Technology

In 1905 Rideal in England first demonstrated that although absolute sterilization of sewage required large quantities of chlorin, a reasonable purification, comparable to that attained by ordinary processes of filtration, could be attained with very small amounts. Prof. Phelps, at the Sanitary Research Laboratory of the Massachusetts Institute of Technology, and later at Red Bank, N. J. and Baltimore, Md., confirmed and extended these conclusions, and between 1906 and 1909 firmly est shed the practice of sewage isinfection upon a practical basis.[*]

The treatment of water supplies by bleaching powder was a different problem however; and the credit for this great advance rests with Mr. G. A. Johnson and his associates, who designed the purification plants at the Chicago yards and at Jersey City, N. J. Both of these problems presen nique and interesting features. At the stock yards the at t was made to purify the water, or more properly, the sewage, Bubbly Creek so as to make it fit for cattle to drink. Mechanical filtration, combined with copper sulphate treatment proved unsatisfactory on account of the enormous amount of organic pollution. The substitution of bleaching powder gave much better results. In the tests reported in the Engineering Record (Vol. LVIII, 659) bacterial counts between 225,000 and 1,390,000 per cubic centimeter were reduced to between 1 and 55. *B. coli* was generally absent from the filtered water. The cost during the official test was $15.66 per million gallons. The plant has been in operation since the autumn of 1908 and has given satisfaction to the stock yards company, although the City of Chicago does not consider the source of supply a safe one and has passed an ordinance forbidding the taking of such waters.

At Jersey City the problem was quite a different one. A heavily polluted stream, the Rockaway River, flows through a large reservoir at Boonton and is generally well-purified by storage. At times of low water followed by heavy rains, however, polluting material is carried quickly across the end of the reservoir and the purification is inadequate. To meet this condition the East Jersey Water Company, under the direction of Mr. Johnson and Dr. J. L. Leal, installed a chlorin plant for treating the whole supply of Jersey City, 40 million gallons a day. Bleaching powder alone is added, with no filtration, and the small dose of from .2 to 1.4 parts of available chlorin per million reduces the bacteria from 30-1600 in the raw water to an average of less than 15 per c. c., according to the records of the water company's experts.* Free water power is available, reducing the cost to the nominal figures of 14 cents per million gallons (quoting again from Mr. Johnson's estimates).

---

[*] Phelps, E. B. The Disinfection of Sewage and Sewage Filter Effluents. Water-Supply Paper No. 229, U. S. Geological Survey.

The Jersey City plant has been in operation now for over a year. As in the case of Chicago the question whether this particular supply of water is or is not a pure and wholesome one has been extensively debated before the courts. The fact that chlorin compounds exert a remarkable bactericidal action has however been amply established; and the cost of treatment is much less than that of any other system of water purification. Chlorin has been used with apparent success at Poughkeepsie, N. Y., and Indianapolis, Ind., in conjunction with slow sand filtration, and at Cincinnati, Ohio, Little Falls, N. J., Harrisburg, Pa., and many other places as a preliminary to mechanical filtration. In connection with the latter process it is clear from the practical results obtained, as well as from valuable experimental studies at the Lawrence Experiment Station of the Massachusetts State Board of Health, that the cost of treatment can be materially reduced by the reduction in coagulant which is made possible by the use of hypochlorite. Without any filtration at all, hypochlorites have been used for disinfecting suspicious well supplies at Corning, N. Y., and Ridgewood, N. J. The scandalous condition of the Montreal water supply has been greatly improved by a similar treatment and the usual winter epidemic of typhoid cut abruptly short. Altogether it is said that the supplies of some hundred cities and towns are receiving chlorin treatment in some form or other at the present time.

There is no doubt that hypochlorite disinfection has come to stay, as a permanent and important part of the armamentarium of the water works engineer. It is particularly desirable therefor that the field for its legitimate use should be defined, so that it may be protected from the unwise use which so often leads to the discredit of new discoveries. Mechanical difficulties having been successfully overcome, the engineer and the chemist are enthusiastic over ss. The sanitarian must however have his word s its bearing on the public health; and he finds that the novel cess involves serious problems, to some of which the answer is yet clear. In studying the results of disinfection both at Jersey and Chicago, from the standpoint of the city authorities, it has sed to me increasingly important to formulate a clear concep- as to what chlorin can and cannot do.

---

*Engineering News, (LXI, 697).

It is quite certain that hypochlorite, added in proper amounts, ll produce a very high percentage reduction of ordinary water eria and of intestinal forms of the *B. coli* group. Its bacterial iency, measured in this way, is equal or superior to that of the linary water filter of either type. In order to effect this result wever, the amount of disinfectant must be adjusted to the ount of organic matter in the water, since chlorin is taken up some forms of organic matter more promptly than by the bac- ria. Thus Jersey City water has received for much of the time ly .2 part of available chlorin per million, while Bubbly Creek water requires 2 parts. The sewage effluent from a trickling filter n be treated with 5 parts and crude sewage with 10 to 15. With sudden variations in organic content there is danger that the proc- s may fail, unless a large excess of chlorin be added at ordinary mes, for it is usually impossible to determine such changes until a considerable volume of raw water has passed the purifying works. General experience, both at Chicago and at Jersey City, indicates that with skilled supervision a high degree of purity can be maintained for long periods. The experts for Jersey City were however of the opinion that on several occasions, following sudden rains, polluted water did pass the Boonton works and was apparent on analysis at the city. It is clear that irregularity of operation due to variations in raw water, must be carefully guarded against. All devices are fallible of course, but in the slow sand filter an increase in organic content only increases the percentage efficiency of bacterial purification, and with a mechanical filter it is possible to gauge the amount of alum promptly by turbidity standards and a slight excess would do no serious harm. Too large a dose of chlorin on the other hand would quickly produce odors in the water and the danger of miscalculation is more imminent.

The second point on which further light is desirable in regard to the sanitary value of disinfection, concerns the selective bactericidal action of chlorin. A filter, since its working is mainly mechanical, acts in a general way alike on all bacterial cells. Thus it is fair to take the gelatin count and the *B. coli* determination as typical of the reduction in other forms. With a disinfectant the case is very different. There are at least three distinct grades of resistance to bactericidal agents, manifested respectively by ordinary vegetative cells, by cells provided with a fatty envelope and by true spores. The effect of chlorin upon colon bacilli may be considered as representative of its action upon bacteria of the first class, probably including such organisms as those which cause typhoid, and cholera and dysentery. The bacteria whose cells contain a large amount of fatty material are much more resistant. Thus antiformin, a preparation containing hypochlorite and caustic soda as its active agents, is used as an aid in demonstrating tubercle bacilli in the sputum, because it destroys and dissolves the ordinary bacteria without affecting the *B. tuberculosis.* Just how much chlorin would be necessary to destroy tubercle bacilli in water under practical working conditions we do not know. It would probably be in excess of that ordinarily applied, which is nicely adjusted to secure the destruction of such forms as the colon bacillus. This problem is of no small importance, for Sedgwick and MacNutt have shown that tuberculosis is one of the diseases notably diminished by the substitution of a pure for a polluted water.

Even water polluted from agricultural land may bear this organism, since Jordan and Arms have shown that the feces of cattle frequently contain tubercle bacilli. With regard to the spore-bearing bacteria like anthrax the protection afforded by disinfection is practically nil. The standard text-books place the amount of chlorin necessary to destroy anthrax spores between .1 and 3. per cent, quantities far in excess of anything used in the purification of water. With water supplies of fairly good character the danger of anthrax is of course slight, but when heavily polluted sources are used, anthrax may easily be a water-borne disease, as in the outbreak near Corry, Pa., in 1907, which was due to the fact that cattle drank from a brook polluted by tannery liquor. Exact laboratory determinations must be made of the amount of chlorin necessary to kill tubercle bacilli and anthrax spores under the conditions obtaining in water treatment, before there can be any confidence that it will eliminate either of these disease germs.

There remains finally to be considered the problem of organic pollution in water, which is removed to a considerable extent by the various filtration processes and to a much less degree by chlorin treatment. In view of the supreme importance of living disease ns, ticularly of the typhoid bacillus, in water sanitation, it has been the fashion to speak as if such living germs constituted the only danger. When, however, it is seriously maintained that chlorinated sewage, containing a large proportion of decom-osing fecal matter is a safe source of supply, it is well to remember at there are no scientific grounds for such an assumption. Some organic compounds are quite innocuous; but others are not. We know that the products of bacterial decomposition concentrated in the intestine produce auto-intoxications and far-reaching derangements of the body's health. In what dilution such substances cease to be harmful we do not know. Certainly the fact that pneumonia, as well as tuberculosis and infant diarrhoea, are markedly diminished by the introducti water, suggests an influence f some sort upon the vital re f the body, aside from the ransmission of specific germs. y case there is a certain standard of decency and cleanl which must be maintained, aside from established influence life and health. Sewer gas and decaying garbage may not y demonstrable effect upon the death rate; but public senti htly demands their elimination, and so it demands the ex rom water supplies of any large proportion of decomposin nd urine.

What I am saying is not at all e line of merely destructive criticism, but is rather an attempt to outline the limitations which must be recognized if disinfection of water is to be wisely and successfully carried out. Bleaching powder is an immensely important adjunct to the art of water treatment, but in my judgment it holds out no reasonable hope that waters so heavily polluted as to approximate sewages can be made potable by this method any more than by filtration. Even if we knew how much chlorin would be necessary to destroy the more resistant disease germs, which we do not, and if it were proven that the organic compounds present were harmless to health, which is not now proven, the esthetic sense of the community would rightly revolt against such usage.

Disinfection with bleaching powder must take its place with other processes of water treatment as admirably suited for certain specific purposes, but not as a magic cure-all. It is best calculated perhaps to act as a double safeguard, in connection with one of the other recognized procedures, ensuring a completely satisfactory supply at a very slight cost, or, in the case of filtration, with perhaps a net economy. Taking an ordinarily polluted stream as the original source of most water supplies there are now three processes by which it can be treated, storage, filtration and disinfection. A fairly well stored water like that now supplied to the city of Chicago, which is generally pretty safe but not always quite safe, can be rendered unexceptionable by chlorin treatment; and the disinfection of lake and reservoir waters is likely to be one of the most fruitful fields for chlorin treatment. When a surface water is not stored but filtered, either naturally or artifically, disinfection again furnishes a double safeguard and completes the purification process. With the rising standards of sanitation I believe that the use of two out of the three methods of purifying water in combination will more and more come to be the rule. This brilliant new development of water disinfection will thus mean no lowering of the quality of our water supplies in the interest of a false economy, but a new bulwark of the public health, an added protection against the introduction of disease in all its forms.

DISCUSSION.

Chairman: We certainly appreciate this broad and excellent paper by Professor Winslow.

Mr. Burrage: I have been much interested in this use of hypochlorite in the purification of water. I have tried some experiments on the disinfection of water of the swimming pool at the Purdue University gymnasium. I added less than one part of available chlorine by this method to 85,000 gallons of water, and was able to get purification of 99.8 per cent, in bacterial figures. I made no chemical tests. Of course, the water in the swimming pool is dilute sewage. It always shows presence of bacillus coli after swimming. After treatment with the hypochlorite it has never showed bacillus coli. I ran a test for a week not using any hypochlorite, running the tank under the ordinary conditions in which it is cleaned twice a week. This costs the University about ten dollars each time the tank is emptied and cleaned. By running the tank for a week and not emptying, but using 1½ pounds of the bleaching powder at night, the water showed high state of purification. By sprinkling the powder on the surface and allowing it to trickle down through the water I was able to get this high percentage of purification. In the matter of the swimming pool, this treatment is so simple that it can be put into the hands of the night watchman or anybody else. This method of treatment has two important factors, simplicity and cheapness.

ting factor, as I understand it, is not the chlorine,
the oxygen. This nascent oxygen is practically the same as
one, and the prompt freeing of the oxygen in the water and its
ion during the first stages of its freedom I believe are far more
ive than at a later time. The various processes of mixing the
owder in the tanks before distributing to the water, in large
ter purification plants, while effective from the bacterial stand-
int, I think if we make specific tests on specific germs we would
d that the bacterial efficiency will be greater when the oxygen
s fresh, that is when the bleaching powder is just put into the
ater. Therefore I believe that throwing it upon the surface of the
ater, permitting it to sink down slowly, as in the swimming pool,
the time going into solution a l the time freeing this nas-
nt oxygen, is the better way quantity of freshly freed
ns of oxygen, I believe, is tive in disinfecting than is
e hypochlorite that had bee ved in the water for some
me.

Professor Winslow: I should like to ask one question of Pro-
ssor Burrage. I noticed that he expressed an opinion that the
tion was due to nascent oxygen. I should like to know just what
e evidence really is for that idea. Of course, it is in general an
idizing action, but do we know that the liberation of oxygen takes
place in the water rather than in the bodies of the bacteria.

Professor Burrage: The reason for the oxygen being regarded as the active agent is that you can get the bleaching effect with using oxygen and without any chlorine at all, and I think from the fact that bleaching powder has been used as a bleaching agent the bleaching effect has been laid to the door of the chlorine, whereas the actual bleaching agent is the oxygen; and in regard to its action on the bacteria, the oxygen is the thing that is left free in the water. You take the hypochlorous acid. It dissolves in the water, freeing the chlorine for a moment, and that unites immediately with the water to form hydrochloric acid, and that unites with some of the aklalinity there, and the oxygen is the thing that is left to do the oxidizing of the organic matter and the bacteria. Just what the action on the protoplasm is I do not know.

THE NEW YORK PUBLIC LIBRARY
REFERENCE DEPARTMENT

This book is under no circumstances to be taken from the Building

form 410

B'D. DEC 21 1913